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London

1918

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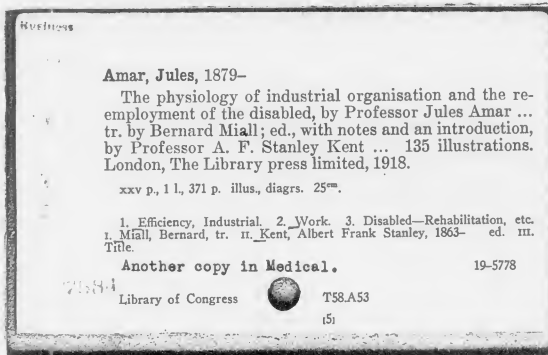
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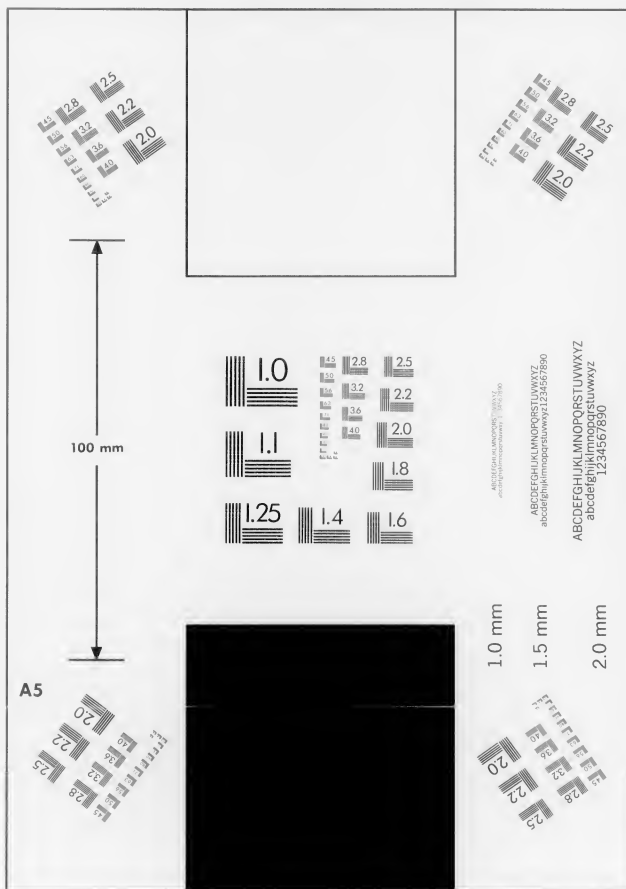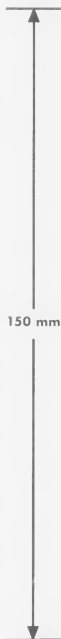ILLUSTRATIONS

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THE

PHYSIOLOGY OF INDUSTRIAL ORGANISATION

AND THE

RE-EMPLOYMENT OF THE DISABLED

The Physiology of

INDUSTRIAL ORGANISATION

AND THE

Re-employment of the Disabled

BY

Professor JULES AMAR

DIRECTOR OF THE LABORATORY OF PHYSIOLOGICAL RESEARCH
IN THE CONSERVATOIRE DES ARTS ET MÉTIERS, PARIS

TRANSLATED BY BERNARD MIALL

EDITED WITH NOTES AND AN INTRODUCTION

BY

Professor A. F. STANLEY KENT M.A., D.Sc. OXON

135 ILLUSTRATIONS

AUTHOR'S PREFACE

To assist in the work of organising labour according to rational
laws ; to assign to each man his true function in the social
machine ; to enable the hale man and the war-cripple to
collaborate in the economic tasks of to-morrow ; to formulate
concisely the doctrine of the maximum utilisation of the
physical and psychical energies, without losing sight of the
moral factor : these are the motives which impelled me to
write this book. It is frankly addressed to the general public,
and it deals, in a pedagogic sense, with the ordinary avocations.
Whether in the matter of physical education and hygiene,
or the organisation of apprenticeship and labour, or that
technical re-education whose programme we have had to
devise, while co-ordinating the efforts made to realise it,
in these sorrowful times it is the duty of each one of us actively
to participate. I have briefly stated why and how.

Further, I have everywhere laid stress upon the intimate
connection between science and economic wealth, between
method and technique and national prosperity.

In the same spirit I have elucidated the problems of pro-
thesis, for France and England might place themselves at
the head of the orthopaedic industry of the whole world, as
of many another industry. The condition is that they must
eschew routine, a factor which enervates the inventive spirit
of the race.

v

My own doctrine has naturally led me to explain and discuss the admirable system of Taylor. I have laid stress upon its essential merits, while correcting it where it appeared to disregard the fundamental laws of fatigue and the conservation of human energy. All our activities, indeed, should be properly conditioned physiologically, or serious miscalculations will result. They are in effect so conditioned by the very laws of nature. But men persist in denying the fact, and seek refuge in abstractions.

In connection with these fundamental problems, therefore, it was necessary to enlighten the reader by means of proofs and data ready to hand. Thanks to a profusion of original and extremely clear illustrations, the comprehension of the text is greatly facilitated. I take this opportunity of thanking my publishers for all the trouble they have taken in this respect. For the benefit of the reader, too, as much as to afford me proof of a goodwill already put to the test, M. H. Le Chatelier, whose name is eloquent of a methodical social activity, has written a Preface for the French edition of this volume, while the Introduction to the English edition has been contributed by Prof. A. F. Stanley Kent, who has also acted as editor.

Whether by author or publishers, the data have been interpreted accurately and sincerely. A book which professes to teach anything should be, as it were, an act of conscience. I trust this may be such a book.

PREFACE TO FRENCH EDITION

In his " Principles of the Scientific Organisation of Labour " (p. 67) F. Taylor complains that the experiments of physiologists and engineers have hitherto afforded no indications as to the endurance of the human being. " The results of these investigations," he says, " have been so negligible that it has been impossible to deduce therefrom a law of any value." The object of M. Amar's present volume is precisely to fill this hiatus, and to show how the experimental methods of the physiologists will enable us, in future, to grapple with the problem of human fatigue and human activity. This problem is of the highest importance from the standpoint of the organisation of labour in factory and workshop.

Before I fully express my appreciation of this volume, I should like to make a few remarks as to the author's criticisms of Taylor's work. He insists, perhaps more than is reasonable, on the insufficiency of Taylor's methods of estimating fatigue in manual workers. This reproach ought, in all fairness, to be addressed to the physiologists. It is not the business of the engineer to invent these new methods of measurement ; he can only employ those which are already extant. Thus Taylor made use of chemical analysis, the measurement of temperatures, and the measurement of the efforts exerted upon tools and implements. He would, similarly, have employed methods of estimating human fatigue, if such

methods had existed. He complains, with perfect justice, that he found nothing to the point in the works of his predecessors. Let us hope that this volume of M. Amar's will help to remove this difficulty.

The reproach that Taylor neglected the part played by the will in the production of labour is, in my opinion, equally unfounded. The example of Rachel, which is cited in this connection, is completely typical. The will cannot supply the place of physical strength ; it merely enables a man to labour in excess of his strength, to over-work himself. This was certainly the case with Rachel, who died at thirty-seven. This is not an example to be imitated. The scientific organisation of labour, as conceived by Taylor, aims at obtaining from the worker the maximum of work which he can normally accomplish, but it does not urge him to exceed this limit by an effort of the will.

These reservations apart, I am delighted to call attention to the profit and the interest to be derived from the perusal of M. Amar's work on the physiological organisation of labour. This volume is not intended only for the specialist, the physician, the physiologist, or the engineer ; any cultivated reader will take pleasure in learning something of the many contemporary problems here considered : problems of the measurement and registration of muscular or nervous fatigue ; of psycho-physiological relations ; of normal alimentation ; of the art of economical labour, whether physical or intellectual ; of handicrafts and apprenticeship ; of the re-education of war-cripples ; of orthopaedy, etc.

M. Amar describes in detail the methods of measurement employed in physiological laboratories for the evaluation of work done. It is to be hoped that numerous investigations

will be undertaken by the aid of these methods, which admit of extreme precision, and owe not a little to M. Amar. The problem to be solved is in reality extremely complex. It is not enough to determine the degree of fatigue occasioned by a given task in order to decide whether the task in question does or does not exceed the capacities of the worker who is the subject of experiment. All serious muscular labour necessarily involves a certain amount of fatigue, but this will not be in any way harmful if the periods of repose intercalated during labour allow the human machine to re-establish itself without permanent deterioration. A steam-engine cannot work without consuming coal ; but there is no trouble as long as it is fed sufficiently, so that it does not come to a standstill. Similarly, in the case of man, the consumption of energy produces no bad results provided nourishment and sleep suffice to make good all losses. Fatigue, far from being injurious, is highly favourable to health. A peasant, who will frequently work sixteen hours a day, will often attain an age of eighty years, while a small shopkeeper in a big city, who does not always do an hour's work in the day, will hardly reach his sixtieth year. It is this that makes the study of overwork so difficult. The man who never fatigues himself does not live long. On the other hand, the man who experiences fatigue often enjoys a hale old age. The great manufacturer Solvay furnishes a remarkable example of this fact. About his sixtieth year he began to indulge in Alpine climbing, regulating the speed at which he climbed so as to maintain the rate of his pulse at 120 beats a minute. This undoubtedly means great fatigue, and Solvay to-day bears his sixty-seven years lightly, overtaxing himself yet further by intellectual labours which are so severe that they often result in loss of sleep. It is true that not

every man could endure such a regimen ; it is no less true that the question of harmful over-exertion is an extremely complex problem, which will demand much investigation before it is completely solved.

The employment of the methods of measurement recommended by M. Amar will assuredly produce an immediate result in such investigations as relate to the re-education of wounded men and war-cripples. The numerous examples which he gives of such investigations show us how it is possible, by methodical experiment, to secure a rapid reduction of the efforts which are necessary at the outset for the accomplishment of a task for which one has had no training.

The systematic evaluation of these efforts makes it possible very greatly to shorten the period of re-education, and will in a great measure help to alleviate the hardships caused by the war.

This particular application of the Taylorian system will therefore be productive of another very happy result : that is, it will provide employment for war-cripples. One of the most essential points of this system is to replace a large number of manual workers in workshop and factory by employees whose office it is to investigate the best methods of labour, to teach these to the workers, and finally to establish the amount of the day's task. The majority of these functions may, for the most part, very usefully be entrusted to wounded soldiers. A personal experience of manual labour is indispensable to the proper fulfilment of these functions, but these latter do not necessitate the personal execution of the particular work in hand. Ex-artisans, for instance, will be able to utilise the experience which they acquired when they still enjoyed the full use of all their limbs. This utilisation of crippled

working-men has been tried, with abundant success, by M. de Fréminville, in the Penhoete workshops, at Saint-Nazaire. This is an experiment which deserves further development. It is true that such advisory work requires, in addition to a technical knowledge of the craft, an adequate amount of intelligence. But just as blind men find that their acoustic sensibility is developed by the concentration of their attention upon those senses which remain intact, so we may count upon a development of the intellectual faculties in men deprived of part of their physical activity. By the very force of circumstances they will direct their energies into fresh channels. At all events, the more intelligent will in this manner be able to find immediate employment for their faculties.

M. Amar's volume touches upon a very large number of problems which possess a great significance in respect of the future of the belligerent nations. Let us hope that he will have many readers, who will not fail to realise the extreme importance of these questions.

HENRY LE CHATELIER.

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INTRODUCTION

THE past few years must ever prove a period of absorbing interest to students of industrial problems. Old forces now first showed appreciable results ; new forces made themselves felt. Fear is felt by many for the years to come, and indeed there is sufficient cause, for dangers lie ahead. But there still exists a means of averting these dangers if we can see clearly enough to recognise it and do not put off action until it is too late. For many years knowledge has been growing, and it is in the application of this knowledge to-day that hope may lie. Engineers have done their best to improve plant, method, and machinery. Invention has followed invention, and automatic machinery has become well-nigh human. One unused to factories is tempted to ask, 'Where is man required?' On the human side progress has been slower. Nearly a hundred years ago the principle was stated that man himself is the most important instrument of industry, but hardly ever is he studied as machinery has been studied. Masters of the old school abhorred all thought of interference with their workmen, and workmen did not welcome interference. Now both are wiser.

About fifty years ago, by an accident fortunate in its results, a young American, about to join his college, was prevented from continuing his studies and went to work instead. He liked the new conditions, and soon rose to a position of authority, but to his surprise was quite unable to obtain

from those below him a satisfactory tale of work. Unlike many in his position he was unwilling to accept short measure, even where short measure was so common, but spent much time, energy, and money in seeking out the cause. Finally he found it, and by his methods proved it easy not only to obtain an output sufficient to satisfy his former requisition, but far more than this.

From Taylor's methods developed later a system which has been widely used. It has been modified and extended, not only in the country of its birth, and through the work of Taylor's great successor, Gilbreth, but also in other countries and in other hands.

It may be asked " Why, if so useful, is not Taylor's system universal ? " The answer is, " Partly because of early prejudice, partly because of certain inherent difficulties." Prejudice was roused by some of those with whom the fate of Taylor's system rested. They lacked discretion, and their methods, introduced unwisely, were suspected, misunderstood, and rejected by the men. Had tact been used, and the workmen encouraged to understand the system, all would have been well. Difficulties arose from the small number of those acquainted with the system, and from the time, skill, and money needed for its installation.

Those times have passed. The men themselves, conscious that high wages and much leisure go with Taylorism, often support it strongly, and, when war broke out, it was advancing rapidly, not only in the factories of America and of Europe, but in those of Asia also.

The system introduced by Taylor and since extended has done much to help the workman. It has given him high wages, short hours, surroundings the best that money can secure.

For capital it has done no less, since by its means output has been raised, and working costs decreased. From the scientific side it may perhaps be criticised because, though dealing with complex problems of physiology, it is founded on trial and error, and concerns itself with results of immediate usefulness, rather than with experimental investigation of fundamental facts. For this reason it was not possible to formulate rules of general application for the conduct of industrial processes. Each occupation needed to be studied separately and apart from others. Thus much time was necessary, and to this need for time must be attributed the tardy introduction of Taylorism and scientific management into industry after the first prejudice had died.

The matter now enters upon a new phase, and experiments on stricter lines are in progress. Thanks to the patience and ingenuity of the Gilbreths in America, measurements of time and space of greatest accuracy are constantly employed, and a knowledge of their value in this connection is extending to other countries. In England inquiries have been made into the influence of fatigue on labour, and into the conditions upon which fatigue depends, as well as into a great variety of the circumstances of industrial occupations. And fundamental data are now being sought, applicable to all employments, so that time may be economised. In France the direction taken was somewhat different, an attempt being made to scrutinise the results of Taylor's methods in the light of accurate measurements of push and pull, pressure and force required in various occupations, and to introduce improvements where need for these was shown. The happy facility which the French possess of devising instruments of greatest delicacy and of employing them to useful ends made this

easy, and results of value were soon obtained. Especially is this true of M. Amar, appointed by the Minister of Labour to investigate the methods of Scientific Management and to adapt it to new needs and circumstances. Few physiologists had turned their attention to the organisation of labour, though the whole matter rests on physiology, and therefore it was expected that the methods of the physiological laboratory would prove most fruitful. The way in which those methods were employed is described by M. Amar so clearly and with such wealth of illustration in his book that it may be followed with ease not only by the expert but also by the ordinary reader. The book indeed is written to be understood by the people, and its appeal is largely to those unfamiliar with the difficult ways of science. But like all else the book is over-shadowed by the war, and its appeal to many will rest upon the fact that its reference is not solely to the normal individual, but also and in large measure to the crippled. In this direction M. Amar is a successful pioneer, and at a time when every endeavour is being made to help those disabled in the war, it is a matter of the highest interest to be assured that eighty per cent. of the victims of amputation should be found capable of re-education to such a pitch as to enable them to re-enter their former occupation, or another sufficiently like it to make their old experience useful, whilst even for the remainder there is hope of honourable independence.

So great indeed will be the interest aroused by this particular aspect of the work that there is some probability of our forgetting that industry has her victims no less than war. Yet for the former, as for the latter, the methods of M. Amar are available, and should lead to results no less admirable.

These aspects of the subject are of great and compelling interest. There is yet another. It is that of reconstruction —not of broken men, but of broken industries. The work carried out in America, in England, and in France must be relied upon as our chief security against industrial chaos. In it we possess a means of organising industry upon new lines so as to provide an increased output and lowered costs at the same time that shorter hours are worked, and leisure greater than even before is secured to the working man. Through lowered costs and increased output high wages may be maintained ; more leisure should give rise to higher development amongst the workers.

The author then appeals to us on three distinct accounts. He shows us, first, how those crippled in the war, and second, how those crippled in industry, may be restored to usefulness, and, further, he contributes to that knowledge upon which our hope of future prosperity depends.

Bristol, 1918.　　　　　　　A. F. STANLEY KENT.

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CHAPTER I

HUMAN LABOUR—ITS HISTORY AND ITS DOCTRINES

I. On the 25th of January, 1829, when opening his course of lectures upon Geometry and Applied Mechanics, of which subjects he was the professor, at the Conservatoire des Arts et Métiers, Baron Charles Dupin delivered the following remarks :

" Men have concerned themselves very largely with perfecting the machinery, the instruments, the material implements, which the worker employs in the mechanical arts. But they have hardly ever concerned themselves with perfecting the worker himself. Yet even if he should be regarded as an instrument, a tool, a source of motive power, he ought to be placed in the front rank of all instruments and all mechanical agents, because he possesses the inestimable advantage of being an instrument which watches and corrects itself, a motor which starts or stops itself, at the bidding of its own intelligence, and which perfects itself by means of thought no less than by means of labour." [1]

[1] Charles Dupin (1784-1873), a French geometrician and economist of great originality.

Dupin, as a matter of fact, in concert with Poncelet,[1] had lately entered upon an admirable campaign in favour of the diffusion of ideas of method, and of teaching the handicrafts in labour centres. He was also anxious that the theory of *fatigue* should be investigated, and that the worker should be protected from *over-exertion*. But the movement came to nothing ; firstly, on account of the chimerical and over-generous temper of which Dupin was accused, and secondly, because 1830 was approaching. Charles X. was solicited for his patronage, but he did not respond ; he had something better to do—namely, to make his departure. Lastly, the theory of the *transformation of energy* was yet unborn ; the majority of scientists, if not all, accepted the doctrine of *vital forces*, which were supposed to be immaterial, and therefore beyond the scope of our methods of measurement.

As for the workers of France, they were hardly aware either of their rights or of their duties ; extremely uneducated, they swept out the factories in which workers of a different nationality—chiefly Englishmen—provided the labour. And a French Minister, on visiting one of these establishments, merely wondered at the sight ; the contrast was obviously enough to shock his feelings.

Despite this official indifference, Dupin and Poncelet succeeded in creating teaching centres of a modest kind, which very quickly became popular, in Paris, Metz, and Rochefort. Unfortunately, for lack of resources, and in the absence of experimental work, the *science of human labour* remained as backward as before ; the physiologists and economists seemed even to despair of such a science.

Only in our own times, and above all since 1890, has it made its way, by triumphant stages, to those heights from which it now sheds so brilliant a radiance. It owes this success to two different methods : the *method of the physicists*, and that of the *physiologists*. We will consider these separately.[2]

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[1] Jean-Victor Poncelet, a French mechanician and general, born at Metz in 1788, died 1867.

[2] See, in *La Technique Moderne*, 1 May, 1914, an interesting historical sketch from the pen of Henri Verne.

II.—A. PHYSICAL RESEARCH.—Familiar, from all times, with the arts and crafts, and almost the sole overseers of labour, the engineers were the first to investigate the subject of human labour. But even the ablest confined themselves to determining the maximum of effort or of pace ; more rarely they turned their attention to *continuous and protracted action*. These experiments, which were very incomplete, were, however, witnessed by the princes of the Court, especially during the reign of the Great Monarch. De La Hire (1640-1718) and Amontons (1633-1703) made tentative experiments ; the Bernouilli brothers, and at a later date Euler, endeavoured to determine the mathematical formula of the *maximum of work*.[1]

In 1722 the Chevalier De Camus, a native of Lorraine, gave proof of a genuinely practical mind by writing his *Treatise on Moving Forces*, in plain and simple language, " for the use of working men." He defined the *centre of gravity*, demonstrating its importance in all our movements and attitudes, and in connection with fatigue. " When two men are carrying a burden," he explains, " the taller man is less heavily laden than the shorter, and the higher the tall man raises the load, the less heavily is he burdened, and the more heavily he burdens the short man " (p. 34). And so forth, in connection with various circumstances of manual labour.

No book could have been better adapted to inculcate the husbanding of human energies, or to instruct the working-man, than the work of this worthy gentleman.

Vauban,[2] in a little work entitled *Le Directeur-general des fortifications*, which was apparently published in the year 1680, gave information which had more experience behind it and was of wider range. It referred to *earthworks*, *embankments*, etc. (*terrassements*). I select from it this observation : " I am confident," says Vauban, " that no one who has had

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[1] Jules Amar, *Le Moteur Humain*, p. 235.

[2] Sébastien Le Prestre de Vauban (1633-1707), Marshal of France, and an eminent engineer ; disgraced on account of his book, *La Dîme royale*, in which he put forward a plea for equality of taxation.

a little experience in the control of labour can fail to agree that four men who are *well supervised* do more work than six men who are left to their own discretion." . . . And in 1729 Bélidor, who was also a military engineer, declared : " Supervision costs less than the diminution of labour to which its absence gives rise." And elsewhere he says : " It is certain that ten hours' work from a man who has his own interest for foreman is worth at least fifteen hours from another whose daily wage is fixed.[1] To drive men further than this is to overstrain them, to risk their falling ill, or failing to hold out for any length of time." We hear the first lispings of the *Contrat social* when Bélidor protests in favour of easier conditions of life for the workers, in view of " the dearness of victuals "—or the generous echoes of the great voice which fell silent after the *Dîme royale*. This scientific courage struck the hour of awakening conscience.

III. **Coulomb.**—We must go to Coulomb[2] for a really interesting description of fatigue, and of the estimation and comparison of the various forms of human labour. This physicist, the greatest of the eighteenth century, was sent to Martinique as an officer in the engineers. There he made the evaluations in question, dealing with workers paid by the piece. Thanks to skilful measurements in respect of the carrying of burdens, the working of cranks, winches, and pile-drivers, and the operations of husbandry, he was able to collect material for an admirable study of human energies— his *Mémoire sur la force des hommes*. Written in 1785, this memoir did not see the light until 1798, when M. de Coulomb had made way for " Citizen Coulomb, of the Institute."

Let us select a few remarks of a general character : " It appears," says Coulomb, " that the method of dividing the labour of men who carry heavy burdens into *brief intervals* of action and repose is that which is best adapted to the animal economy, and that men prefer to walk quickly for a few moments, and then to rest completely for a few moments,

[1] This proportion of 2 to 3 had already been given by Vauban.
[2] Charles-Auguste de Coulomb (1736-1806), born at Angoulême.

to covering the same distance in a time equal to these two intervals, at a slower but more continuous pace." And the amount of labour thus performed " varies according to ability, the selection of workers, *food* . . . and *climate*." These two last factors of the human output, food and climate, are here stated for the first time. They are essential *physiological* factors, and Coulomb adds a hint of a *psychological* order as to the method of investigation. " It is necessary," he says, " to observe a good workman, who is paid by the piece ; at the same time, he must not be aware that he is under observation, lest this should affect his work for the time being."

Up to the close of the nineteenth century no more important work than Coulomb's had appeared. His ideas were expressed in different forms ; men borrowed from his observations, and, above all, exaggerated their value, since they were, for the most part, based upon a single direct determination : while in other instances Coulomb borrowed from his predecessors, with unfortunate results.

But of late years the method of these old engineers has been elucidated by the brilliant research work, both practical and theoretical, of an American engineer, Frederic Taylor.

IV. **The Taylor System.**—Taylor's principles of the organisation of labour assuredly constitute the most comprehensive system known to industry. They teach the sovereign power of mathematical certainties, of *method*, and of *order*, of which they are the pure expression.[1]

Frederic Winslow Taylor (Fig. 1) was born in 1856, in Germantown, Pennsylvania, and died in Philadelphia on the 21st of March, 1915. From the position of a common porter, he gradually rose to the dignity of engineer, and then to that of factory manager. His persistent industry and his great technical and practical intelligence quickly caused him to be appreciated ; while his original work in the economic domain made him famous all the world over, and brought

[1] See *Le Moteur Humain*, pp. 343, 496, *et seq.*, and H. Le Chatelier in the *Revue de Métallurgie*, p. 185, April, 1915.

him legitimate wealth. He was the first to succeed in *organising human labour in a rational and scientific manner.*

To attain this object, he entered upon two simultaneous undertakings :

1. Organisation of plant.— First of all, it was necessary to constitute a highly perfected plant or equipment, which should realise the *form*, the *dimensions*, the *weight*, and the *quality* calculated to result in speedy work. It was necessary to undertake the scientific investigation of this particular point ; but such investigations are almost always refused by the manufacturer, because they cost him money, and he does not perceive their *immediate* utility.

FIG. 1.—F. W. Taylor (1856-1915).

Taylor managed to triumph over this reluctance, and was able to spend more than £40,000 in laboratory research, during a period of nearly twenty-five years (1880 to 1903) ; and assuredly time and money could not have been better employed.

2. Organisation of labour.—It was then necessary to form a staff adapted to this technique and these conditions of *speed* ; a staff, consequently, of which each member was really in his right place, whether he gave orders or obeyed them ; and it was necessary to train this staff. This was a most difficult task, but Taylor's tenacity was victorious.

As for instructions relating to the preparation and execution of work, these were given in writing, on *instruction cards*, and the workers were taught to interpret them without hesitation. Above all, they were shown what movements

are required in the use of a given tool or a given process, and what movements should be dispensed with, as they are usually made without reflection, and are consequently without profit. *Those movements which are useful should be performed in a minimum time, and other movements should be avoided.*

To satisfy this *law of economy* Taylor had to *time* the different actions and movements of the worker, retaining only those whose efficacy was not doubtful. And as all those enlisted by industry could not break themselves in to this mode of activity,
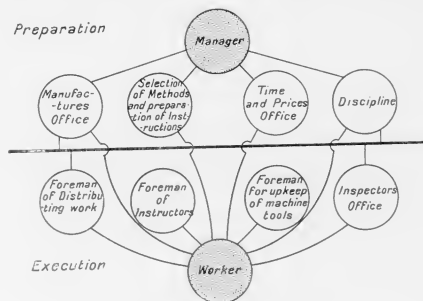
FIG. 2.—Scheme of the Taylor System of Organisation.

he retained only the more capable. So that *timing and selection are the two characteristics of the Taylor method.*

For example, the handling of a casting is in question. The time required for this operation will be analysed as follows : removing the casting from the ground or stack ; carrying the said burden ; placing the burden on the ground or depositing it upon a stack ; returning empty-handed. The analysis is made, as Coulomb advised (p. 111.), as a result of the examination of a capable and healthy worker, paid by the piece, who is taken as a *model*, and, to a certain extent, as a *standard.*

The workers are then trained by instructors with a view to attaining the output of the model worker ; both the movements to be made and the safeguards against delay being recorded on the cards which are given to them. *Apprenticeship* becomes rapid and methodical, and there is, in every workshop, an intense functional life, in which time is literally money. The connection of the various functions is pretty well symbolised by the chart here given (Fig. 2). It leaves no room for any cause of waste or delay. It reflects order and measurement.

V. **Advantages of the Taylor System**.—In foundries especially these principles yielded surprising results. In a matter as simple as the removal of pigs of cast iron, the load transported was increased to 47 tons per man per day, as against the usual 12 or 13 tons. That is, the useful effort of the worker was multiplied *fourfold*.

But Taylorism has a character of *universality ;* it can be applied to all branches of industry ; to industrial, agricultural, and commercial work ; a point upon which especial stress has been laid.

Here is an illustrative anecdote : A disciple of Taylor, the engineer Frank Gilbreth, having visited the Anglo-Japanese Exhibition in London, saw there a young girl who was placing circulars in blacking-boxes with a wonderful and instinctive dexterity. He had no sooner considered her task than he began to note her movements and to time them. *Forty seconds* were needed to prepare twenty-four boxes. Gilbreth then informed the young woman that she was not going the quickest way to work. Very sure of her dexterity, she scoffed at him, but finally consented to omit the movements which he considered useless. As she was on piecework, she was tempted by the idea of increased wages. In a few days she succeeded in handling the twenty-four boxes, not in forty seconds, but in *twenty-six.* She admitted, moreover, that the work seemed less fatiguing.

Little things teach important lessons.

The American method, then, possesses an educative virtue ;

it comprises incontestable scientific truths. It is, in a word, *method* ; that is to say, order and harmony.

The worker who moves to the right and the left in search of his tools, who is forever coming and going, repeating the same process day by day, while his work awaits his convenience ; the manufacturer who refuses to introduce those changes in his staff and his plant which his works require ; and the man who, in his office, is constantly mislaying his pen, or his notes, or a letter received ; are they not living examples of the rule-of-thumb and the lack of order which Taylor condemned ?

Henceforth the *uneconomical* results of the ordinary clumsiness of human beings are plainly evident. Great and small may, in the light of this doctrine, follow a scientific discipline and enter upon the *true apprenticeship,* the *apprenticeship to order.* Beginners will not fatigue themselves in vain ; they will quickly become adroit and skilful in their craft. Any man engaged upon piecework, and anxious to increase his earnings, is thus won over to the method. To be sure, selection can only be effected by means of elimination ; and many workers who would like to adopt this or that calling find themselves ousted by men more capable than themselves. However, they are not necessarily reduced to poverty. As Taylor remarks—and his words are even truer to-day—" There is at present such a demand for labour that no working-man is forced to be idle for more than a day or two; so that the less capable workers are not more unfortunate than before. Instead of pitying them we ought, on the contrary, to congratulate ourselves, and rejoice that a great number of valuable workers have at least the chance of earning high wages, and of progressing towards prosperity."

VI. **Criticisms of the Taylor System**.—Taylor's system of organisation, admirable as it is, lies open to certain criticisms which apply not to it alone, but to all the mechanical theories of human labour, whose elucidation we have postponed to the present moment.

1. *The Taylor system lacks elasticity.*—An extremely strict

adaptation of the man to his task, and a differentiation of the various departments of labour, which is carried to great lengths, and is at the same time extremely definite, are justified in theory, but in practice they are impossible, if we reflect, on the one hand, that a more urgent demand is made of labour, and, on the other hand, that the latter tends to become less plentiful. We are therefore obliged, to some extent, to exercise less severity in selecting workers, and to compromise in the matter of *quality*—which we require to be of a superior degree—in order to obtain the desired *quantity*. We are not only obliged to do so ; we *ought* to relax the principles of the system, unless we wish to deny the fact of adaptability and the influence of the will. A given worker, who, during a first test, does not seem suitable as a Taylorian model or standard, will become so by force of application. In the province of art we might instance the case of the great Rachel, whose *vocation* would have been destroyed by the application of Taylorism. Vocation is precisely the word : the American principles discourage the fulfilment of a vocation, for the latter comprises a non-mechanical element which escapes calculation and prevision.

In other words, a civilised man, even though imperfectly educated, possesses reserves of moral energy which may enable him to overcome many difficulties, and accelerate the process of shaping him as a worker.

We cannot entirely disregard these reserves.

The Taylor system, therefore, is wanting in elasticity ; at all events, it should not be too rigidly framed.

2. *The Taylor system is incomplete.*—Even if one were to form model workers in conformity with the rules of the Taylor system, a serious problem would still remain to be solved. The selection of workers and implements enables us only to improve technique and to increase production. But we are not told how the human organism is to be protected from overstrain, and what are actually the physiological conditions under which the best work is performed. Like La Hire, Amontons, and Coulomb, Taylor considered only a part of the human machine—that which performs work ; in other

words, the *instrument*. He neglected the other portion of the whole, from which the implement receives its motive force, and which, on this account, we will call the *motor*.

The receiving instrument and the motor must not be separated when the productive value of the machine is under consideration ; and in the human worker especially they are inseparable. In him, above all, the output of the motor is considerably modified, if it is nourished with good fuel and punctually relieved of the waste products which clog it ; if it is worked at a given speed, and under a given load, rather than at other speeds and under other loads ; and if it is placed in an environment which, so far from impeding its functioning, tends, on the contrary, to favour it.

The Taylor system is admirably devised for training the human implement to work rapidly, and at its best ; but it gives us no information relating to the motor, properly so called.

The American engineer admits, for example, that he has observed signs of " very great fatigue," in the women who *sort the balls for bicycle bearings*. Forced to perform work very quickly, and with *very great attention*, these women are unable to adapt themselves to this kind of labour in a greater proportion than 35 out of 120. The rest have to relinquish it, or they are threatened with nervous exhaustion.

The increasing part played in modern labour by this close attention, and by skill and dexterity, increases the exhaustion of the nervous centres, of cerebral energy, concerning which —and it is the same with muscular energy—Taylor gives us no exact information. But his great experience of men enabled him to avoid many dangers. The result was certainly admirable, and it would inspire confidence if every engineer had an *instinct* equally sure. Observations as to the degree of fatigue produced, made at a glance, cannot replace objective tests and measurements, nor supply the place of the physiological conditions which ought to govern human activity. And of what value would such observations be to-day, in the case of the work performed by war-cripples ? The physiological limitation of great numbers of persons of this class, the necessity of utilising them in good earnest, and the social

problem created by their employment in industry, demand a completer system of scientific control, a system capable of analysing all the factors of human energy.

For these reasons the American doctrine, despite its exact technique, illuminated by the radiance of mathematical research, is nevertheless incomplete, because, like the experiments of the older physicists, it does not take the physiological data into account, nor does it define the normal output of the human motor.

VII.—B. Physiological Research.—With better judgment than the mechanists, the physiologists turned their attention to the exchanges of energy of which the living organism is the theatre, whether during work or repose. In all forms of human activity there is a consumption, an *expense of energy*, which draws upon the reserves of our body-cells, at the expense of *alimentation*.

This energy, the " vital forces " of the older writers, the physiologists are able to measure. A simple comparison will make this clear.

The steam-engine, for example, develops power and heat by burning a combustible, oxydising it by means of the active gas of the atmosphere, *oxygen*. It is obvious that the expenditure of energy, instead of being estimated in terms of carbon, might just as well be expressed in litres of oxygen, the quantity of this gas being strictly proportional to the quantity of fuel which it transforms, with the evolution of heat and work.

Similarly, we observe in the body of the animal a transformation of the food absorbed, by the action of the oxygen respired, together with the production of muscular and nervous work and heat. Skilful experimenters, such as Chaveau, in France, educed the *positive proof* that the animal is the theatre of the same operations as those which are effected in heat engines, although we then knew nothing of the nature of vital combustion.

Energy, in its manifold aspects, originates in these extensive phenomena of oxidation : the energy of our muscles, visible

and measurable ; the energy of thought, mysterious in its essence, and infinitely varied in its manifestations.

This was verified in the magnificent laboratories which were established in Boston by the generosity of Mr. Carnegie.

A *calorimetric chamber*, about 15ft. square, and of about the same height, is arranged for the reception of the human subject. The air supply is so devised that it can be analysed as it enters and as it leaves.
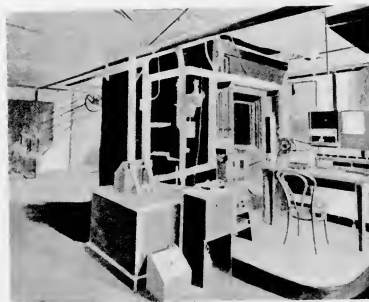
Fig. 3.—Calorimetric Chamber, Boston.

It is even possible to measure, with great exactitude, the heat radiated by the body of the subject. The whole installation, which was described in our volume, *The Human Motor* (*Le Moteur humain*, p. 199), cost more than £10,000 (Fig. 3).

Experiments which were ably directed by Messrs. Atwater and Benedict proved that the quantity of oxygen consumed is strictly regulated by the amount of energy produced, the latter being measured in calories.[1]

[1] The large calorie is in this case the quantity of heat required to raise the temperature of 1 litre of pure water from 0° to 1° Centigrade. To estimate the *kilogram-metres* of work in the same unit, divide the former by 426, there being an equivalence between 426 kilogram-metres of work and 1 calorie.

One litre of oxygen is equivalent to 4·9 calories : that is to say, the various foodstuffs burned by that amount of oxygen in the cells of the body develop as much heat as about two-thirds of a gramme of coal.

Fats, sugars, and albumins are concentrated in the microscopic furnaces of the human machine, under the continual insufflation of oxygen, and liberate energy. Hence the heat which maintains the constant temperature of the body, a temperature of 98·4° Fahr. (almost exactly 37° Cent.), and muscular labour. We shall explain further on how it is possible to measure at any moment, every minute if desired, the consumption of respired oxygen, and to follow the variations of energy which the organism displays under any different set of circumstances. Nothing could be more *reliable* or more *practical* than the method employed.

On the other hand, physiology turns its attention to analysing the phenomena of fatigue, and the manner in which they affect the output of nervous and muscular energy, the functions of circulation and respiration, and the production of organic poisons, or auto-intoxication ; and it aims at defining the normal limits of this fatigue, in order that over-exertion may be avoided with certainty.

We have here, therefore, a profounder and more exact science than the purely mechanical method. This explains why it was recommended in the dawn of *energetics* by the founders of that doctrine : Hirn, de Colmar, and Helmholtz (1848, 1854).

VIII. **Lavoisier.**— But it must be remembered that the most ingenious chemist of modern times, Lavoisier,[1] initiated the era of the measurements and investigations of which we are speaking (Fig. 4). He established the relation between the oxidation of the body and the production of " energies." With his collaborator Seguin as subject, he determined the quantities of oxygen respired, during repose and during labour. With his face covered by a " respirator mask,"

[1] Antoine-Laurent Lavoisier, born in Paris in 1743; died under the guillotine in 1794.

Seguin at first remained motionless ; then, for a quarter of an hour, he raised a weight attached to his feet (Fig. 5).

Fig. 4.—Lavoisier (1743–1794).

From these observations Lavoisier drew the following important conclusions, which cannot too often be quoted :

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" Observations of this class lead to the comparison of the action of forces between which there would seem to be no relation. One can discover, for example, the weight in pounds corresponding to the efforts of a man delivering a speech, or a musician playing an instrument.

" One might even estimate the mechanical component (*ce qu'il y a de mécanique*) in the effort of the philosopher meditating, the man of letters writing, or the musician composing. These efforts, which are regarded as being purely
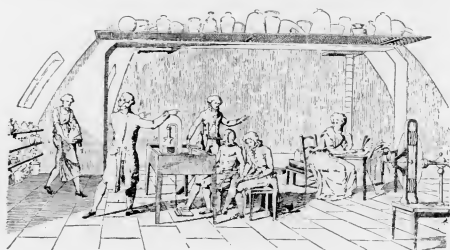
Fig. 5.—Lavoisier's experiment upon Seguin.

mental, have in them something physical and material, which enables us, in this respect, to compare them with those of the labourer. So it is with a certain justice that the French language has confused, under the common denomination of *travail* (work, labour), the efforts of the mind with those of the body, the work of the office and the study with the work of the hired labourer." [1]

These lines, written in 1789, contain the whole physiological doctrine, in its remotest applications. It will be seen how fertile it is ; it does not exclude mechanical measurement ; on the contrary, it includes it, as an element of a higher and completer truth : *the evaluation of vital energy.*

[1] Lavoisier, *Œuvres complètes*, II., p. 688 (authorised edition).

CHAPTER II

THE ORGANIC FUNCTIONS OF MAN

IX.—The question of money is not the only matter in dispute between capital and labour. Human life must be safeguarded.

In order to organise movement, bodily and mental, and to avoid, with certainty, irregularity and waste, it is therefore essential to possess a knowledge of the laws of active life. These laws have acquired an even greater importance since the events of the war have extended the domain to which they are applicable. For humanity has been crushed and bruised ; its wounds are barely cicatrised ; mutilation has reduced the social value of millions of workers ; organic defects, which we must learn to detect, have been produced, and moral sufferings exist whose profound repercussions we must learn to understand.

Let us get closer to the heart of the problem. The coming generations must be healthy and vigorous ; the activity of youth must be organised. The generations about to pass away must counsel youth, must guide it by the light of their experience and their virtues. The duty of science is therefore to investigate the best conditions of life and work.

It is unhappily very true that the majority of our ills are caused by ignorance, and often by our weakness of will. The capital of our energies ought not to become exhausted until the remotest period of old age, if only we understood how to live in a temperate and orderly fashion. We shall do otherwise at our own cost. This is why a knowledge of the functions of the human organism is the preface to all *physical culture*, and to all discipline in labour. It is not a question of describing in detail the innumerable mechanisms of which

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the organism is composed. The physician, like the engineer, has merely to understand the inter-relation of the physiological functions, and their co-ordination in that finer harmony which constitutes health. The normal state and the pathological condition ; the predispositions which exercise favours or aggravates ; the favourable and unfavourable indications, and the conditions, of a rational activity—these are the elements which I shall endeavour to assemble in this book.

The principal functions include *digestion*, *respiration*, and *circulation*, which collaborate together in order to form reserves of energy ; *movement*, which expends and employs this energy ; and *thought*, which is a mode of movement, but invisible, and as yet unexplained. The solidarity or synergy of the whole finds its outlet in the production of *energy*.

X. The Digestive Function.—The digestive apparatus is represented by a group of organs (Fig. 6), which are represented in diagrammatic form in Fig. 7. We see that apart from the duct known as the *oesophagus*, by means of which *nutriment* passes from the mouth to the stomach, through an average distance of some eight inches, the whole of the digestive organs occupy the lower portion of the trunk. They are divided from the upper portion, in which lie the heart and the lungs, by a thick, wide, muscular membrane, a sort of ceiling, called the *diaphragm*.

The different portions of the digestive canal, apart from the oesophagus or gullet, are : the *stomach*, whose *greater curvature* rests upon the *diaphragm* on the left side, almost vertically beneath the heart, and which, when greatly dilated, may incommode the left lung, and react perceptibly on the central organ of the circulation ; the long canal of the *small intestine*, about 25 feet in length and 1·2 inches in diameter, divided into a short, narrow passage, the *duodenum* (about 5 inches in length), the *jejunum*, and the *ileum*; which latter portion opens into the large intestine by the *ileocaecal* valve. The large intestine encircles the smaller ; it is closed at its right-hand extremity by a small, slender *appendix* (the seat
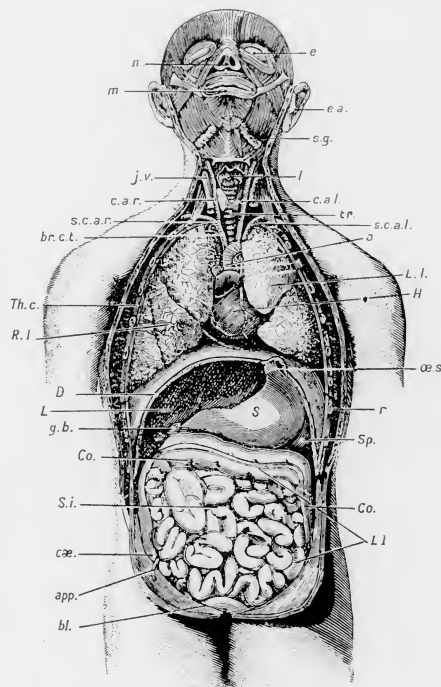
FIG. 6.—Principal Organs of the Human Body.

e, eye ; *n*, nose ; *m*, mouth ; *ea*, ear ; *s.g.*, sub-maxillary gland ; *l*, larynx ; *j.v.*, jugular vein ; *c.a.r.*, *c.a.l.*, right and left hand carotid arteries ; *s.c.a.r.*, *s.c.a.l.*, right and left sub-clavian arteries ; *tr.*, tracheal artery ; *br.c.t.*, brachio-cephalic trunk ; *o*, aorta ; *Th.c.*, thoracic cavity ; *R l.*, *L.l.*, right and left lung ; *H*, heart ; *L*, liver ; *S*, stomach ; *Sp.*, spleen ; *D*, diaphragm ; *oes.*, oesophagus ; *r*, rib ; *g.b.*, gall-bladder ; *Co.*, colon ; *s.i.*, small intestine ; *cae.*, caecum ; *app.*, appendix ; *bl.*, bladder ; *L.I.*, large intestine.

of the well-known *appendicitis*) supposed by Metchnikoff [1] to be a useless organ, which will continue to atrophy until no trace of it remains, Nature suppressing everything that has not a determined function, for she aims at *economy of material*. To the left the intestinal canal becomes almost vertical and rectilinear, whence the name of *rectum* given to this descending portion, which finds its outlet in the *anus*.
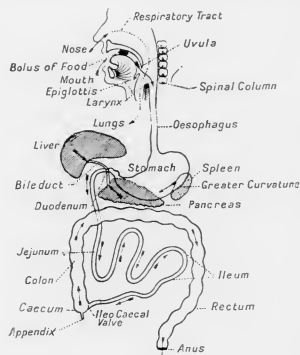
Fig. 7.—Diagram of the Digestive System.

A wide membrane, consisting of two leaves or folds, one of which slides over the other, envelopes the whole digestive system; this is the *peritoneum*. The movement of the stomach and the intestines occurs, therefore, without friction; it is free, but, except in cases of serious falls or violent efforts, it is controlled, and is safeguarded against shocks. The *aliments* absorbed make their way through a canal with muscular walls, tough and elastic, which are animated by progressive contractions which travel toward the *anus*. This *peristalsis* is very rapid during the act of swallowing; it is slow in the stomach, where the food is allowed to remain for the necessary length of time; it is more rapid in the small intestine, but occurs less frequently and with greater violence

[1] The great Russian scientist, assistant-director of the Pasteur Institute, Paris (1845-1916).

in the large intestine. By adding to the food a little *sub-nitrate of bismuth* the digestive canal may be rendered visible by means of the X-rays, when its movements may be studied by means of radio-chrono-photography [1]; it is then seen that the passage of food through the oesophagus alone occupies six seconds,[2] but it remains in the gastro-intestinal organs for from one to several hours.

During these different stages are effected the chemical operations of digestion, under the action of the juices secreted by the internal *mucous membrane* of the walls of the stomach and intestines, aided by the oscillatory movements of the organs themselves, and still more by the fluid secretions poured into them, in the region of the duodenum, by the *special glands* attached to the digestive canal : the *liver*, situated to the right of the stomach, furnishes the *biliary secretion*, a potent factor in the transformation of fats and in antitoxic processes ; while into the duodenum also, and at almost the same point, flows the *pancreatic juice*, whose chemical action upon alimentary substances is varied and energetic.

It is enough to mention these products of the abdominal factory, together with the secretion of the *salivary glands*, to give an idea of the various stages and the total duration of the phenomenon of digestion.

Nothing should disturb or impede the digestive process, either in its internal conditions, which are dependent upon the choice and the quantity of the foodstuffs taken, or in its external conditions, which are normally realised by protection against cold and fatigue.

But an interesting discovery, due to the Russian scientist Pavloff, throws upon this collection of facts the light of a doctrine which might almost be called philosophical. Pavloff states that *the nature of the gastric juice is always adapted to the nature of the food to be digested. The mere sight of this food, or the imaginary conception of it, produces the same result, and*

[1] J. Carvallo, *Archivio du Fisiologia (Compte rendu du Congrès de Heidelberg 1907, Vol. V., p. 97, 1908).

[2] Meltzer, *Centralb f. Med. Wissensch.*, pp. 1-4, 1883.

the psychic secretion is more active and abundant than the secretion produced by the direct contact of the substance.

The old saying as to food "making one's mouth water" is therefore not a nonsensical adage : the entire culinary art, of sauces, and seasonings, and the preparation of food in general, tends to provoke these psychical interventions, which stimulate the appetite and facilitate the work of digestion. To eat one's food "too quickly to get the taste of it," is a fault which is known as *tachyphagia*. Our manifold occupations have created it, to the detriment of our health. One should take one's time to masticate one's food and enjoy its flavour. It is time usefully employed.

When the whole series of phenomena which commence with the work of the teeth (*mastication*) and are terminated by the work of the intestines is completed, when all the useful and essential portion of the food taken has been extracted and the residue evacuated, a complex product is formed : the *chyle*, which has a milky appearance and contains most of the fatty material derived from the meal. Numbers of little suckers or filters, the *villi* and *lacteals*, pump it through the intestinal wall. They conduct it, through the thoracic duct, to the blood, which carries the fatty material to all parts of the body. The excess is stored up eventually in the cells of adipose tissue. Meanwhile, the saccharine and albuminous materials have been absorbed more directly into the blood in the intestinal wall, by which they are carried to the liver, the sugars being there deposited in the form of glycogen as a reserve of carbohydrate material. The albuminous materials—now in the form of amino-acids—are taken to the various cells of the body, and used in rebuilding their substance. The blood will carry off the products of combustion : *urea, water, carbonic acid gas,* and various more or less *toxic bodies.* These are carried in the blood to the *kidneys,* which separate some of them, and to the lungs, which expel the carbonic acid gas. The *urine* then fills the bladder, and is finally eliminated.

We must avoid retarding the renal purification of the blood, for this cleanses the organism; the use of fresh,

wholesome water as a beverage admirably fulfils this service. Neither must we embarrass the stomach by substances which it could not easily digest, or which irritate it. Let us beware of abusing the refined cookery to which our palates are accustomed ; let us protect the stomach against alcohol and spirituous liquors. Thus the *normal* cycle of the phenomena of digestion will be rendered possible.[1]

XI. **The Respiratory Function.**—We must now consider another cycle ; one which is almost invisible, but no less indispensable to life. This is the cycle of the atmospheric *oxygen,* a gas whose function it is to burn all combustible matters, and whose consumption in the heart of the body-cells is regulated by the supply of aliment. Oxygen exists in the air which we breathe in the proportion of 21 *parts* to 79 of nitrogen ; that is, it forms about *one-fifth part of the volume of the air inbreathed.* It enters the lungs by passing through the nasal cavity, the mouth, the pharynx, the larynx, the windpipe, and the bronchial tubes (Fig. 6) ; it is distributed among an enormous number (about two thousand millions) of *pulmonary vesicles,* like so many microscopic pockets ; and in these it finds the fine ramifications of the blood-vessels. The membrane interposed between the blood and the air is no more than a *hundredth part of a millimetre* in thickness (1-2500 inch). The oxygen, by virtue of its proper tension, passes through the membrane and fixes itself in the blood, which thus becomes its universal vehicle, or, in the words of Claude Bernard, "its internal environment." Respiration effects the gaseous exchange by which the blood saturates itself with oxygen and rejects the carbonic acid gas derived from cellular combustion. It comprises the two phases of *inspiration* and *expiration,* which are manifested by the dilatation of the lungs and the whole thorax during a first period of time, and the cessation of this dilatation during the second period, which is usually *longer* than the first.

[1] J. P. Pavloff, *Le Travail des glandes digestives,* passim ; Paris, 1901 ;—A. F. Hornborg, *Skand. Arch. f. physiol.,* Vol. XV., p. 209, 1904 ; this writer verifies Pavloff's laws relating to the digestive system of man.—For details as to earth-eating tribes, see *Le Moteur Humain,* p. 180.

In order that the thoracic cavity may thus increase its volume, the diaphragm sinks downward, pressing on the stomach, and the *ribs*, rotating upon their articulations, are raised and expanded. The result is an increase of the vertical, lateral, and antero-posterior diameters of the thorax, due to the combined and regulated action of the respiratory muscles. The amplification due to the movements of the ribs is greater than that caused by the diaphragm, the ratio being about two to one. This is particularly marked in women, partly on account of the organs of generation, and partly on account of the whims of fashion—that is, corsets. In the female savage the movements of the diaphragm are much more extensive. At each inspiration the adult man draws *half a litre* of air (·88 of a pint) into his lungs, and he renews it, while at rest, some 15 or 16 times per minute. Thus at least *ten cubic metres* (more than two thousand gallons) of air are daily brought into contact with the blood in circulation. When continuous work is being done, whether in the performance of manual labour or in playing games, the consumption of oxygen and the activity of the entire respiratory apparatus is increased, and the ventilation of the lungs attains the rate of 30 to 50 respirations per minute, displacing a volume of air two or three times as great as before. There is an excitation of the nervous centres of the spinal cord in the region of the medulla oblongata, due to the arrival of blood rich in carbon dioxide and oxygen intermixed.[1]

Under these conditions of activity the thoracic movements and the pulmonary passages must be thoroughly *free*. Certain pathological conditions affect the muscles entrusted with these movements, or limit the capacity of the lungs (paralysis, pleurisy, pneumonia); they give rise to early or immediate fatigue. Tight clothing must be avoided, as well as faulty attitudes of the body.

Such conditions as these produce a very irregular ventilation of the lungs during the performance of work; the rhythm of respiration will be rapid, and the respiration itself will be superficial. In such a case the gaseous exchanges are in-

[1] C. Foa, *Archivio di Fisiologia*, Vol. VI., p. 536, 1908-9.

sufficient : a condition known as *dyspnoea*. It occurs during violent exercise (bicycling, mountain-climbing), as the result of anaemia, or in an atmosphere poor in oxygen or rich in carbon dioxide. This last factor is one which should particularly be avoided ; the dyspnoea due to carbonic acid gas is certain to occur if the proportion of gas rises to one-tenth of the volume of the air inbreathed. But its *toxic* effects are perceptible to the nerve-centres when the ratio is much smaller ; they are attributed,[1] but, I believe, without reliable proof, to the presence of traces of *ammonia* in the air expired, or even to certain *alkaloid products*. Brown-Séquard and d'Arsonval reported the presence of these products, which Weichardt and Strœde describe as *kenotoxins*.[2] Despite the investigations of these authorities, however, it must be admitted that in a confined environment, in which healthy persons remain for any length of time, the only factors to be regarded as dangerous are *heat* and *humidity*. This is proved by the fact that if, in such an environment, one breathes through a tube communicating with a dry, cool air-supply, one is none the less incommoded ; while, on the other hand, if the imprisoned air be breathed through a tube by a person outside the chamber, he feels no inconvenience.[3] Hence it is an indispensable precaution to ventilate workshops, dwelling-houses, barracks, etc., and to ensure the passage of a current of fresh air through them. Respiration will then replenish the supply of oxygen to the circulation of the lungs and diminish the depressing effect of moist heat.

XII. **The Circulation.**—The blood is renewed in every part of the body, thanks to the movement impressed upon it by the *heart*, and its renewal maintains the vitality of the tissues. Every cubic millimetre of blood contains about

[1] Formanek, *Arch. f. Hygiene*, Vol. XXXVIII., p. 1, 1900;—Gardenghi, *Giornale d. R. Soc. Ital. d' Igiene*, Vol. XXVI., 1904.

[2] Brown-Séquard and d'Arsonval, *Comptes rendus Acad. Sciences*, Vol. CVI., pp. 106, 165; Vol. CVIII., p. 267, 1888-9;—Weichardt, *Ueber Ermudungstoffe*, 2nd ed., Stuttgart, 1912;—Strœde, *Zeitsch f. Schulges-und-heitspflege*, Vol. XXVI., p. 735, 1913.

[3] L. Hill and Flack, *Bull. mens. office intern. Hyg. Publ.* Vol. VII., p. 776, 1915.
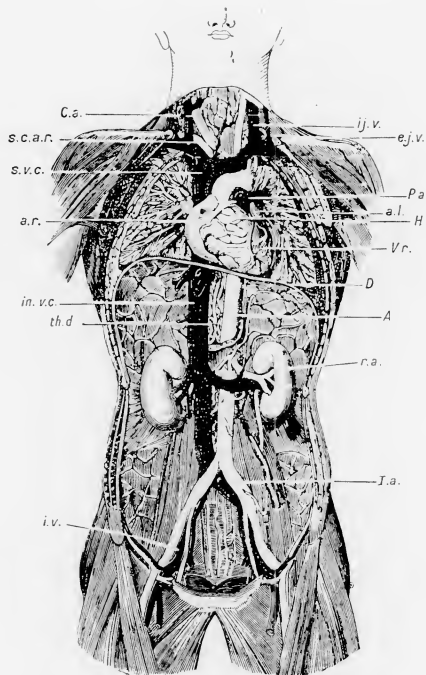
Fig. 8.—The Circulatory System.

H, heart ; *D*, diaphragm ; *a.r.*, *a.l.*, right and left auricles ; *V.r.*, right ventricle ; *A*, aorta ; *C.a.*, carotid arteries ; *s.c.a.r.*, right subclavian artery ; *r a.*, renal artery ; *I.a.*, iliac arteries ; *P.a.*, pulmonary artery ; *s.v.c.*, *in.v.c.*, superior and inferior venae cavae ; *i.v.*, iliac veins ; *i.j.v.*, *e.j.v.*, internal and external jugular veins ; *th.d.*, thoracic duct.

five millions of red corpuscles, albuminous and ferruginous elements, of which the base is *haemoglobin*, and we know that oxygen readily combines with this substance, which thus becomes a reserve of energy.

From the lungs, where it is freed from its carbonic acid gas, and enriched with oxygen, the blood flows toward the left-hand side of the heart through the *pulmonary veins* (Fig. 9),
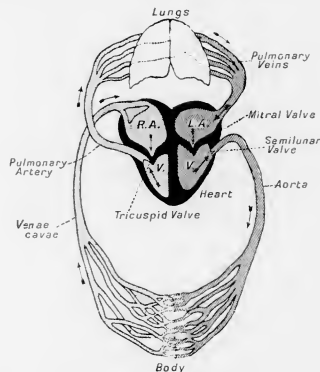
Fig. 9.—Diagram of the Circulatory System.

where it fills the left *auricle*. But this contracts, driving it into the left *ventricle*, while the communicating valve, the *mitral valve*, closes. A powerful contraction of this left ventricle drives the blood into the great artery known as the aorta, with its numerous branches : carotids, jugulars, renal and iliac arteries, etc. (Fig. 8). This is the irrigating system by which all our organs, whether their output be physical force or thought, are replenished. The blood diffuses its nutritive principles through them, and carries off the waste

products of vital combustion. Being then vitiated, with its haemoglobin partially de-oxidised, the blood returns to the heart by the *venae cavae*. It is received by the right auricle, which immediately urges it into the right ventricle, and from this it proceeds to the lungs, for a fresh purification. There is therefore a third cycle, that of the blood, to add to the cycles of respiration and digestion. They ensure an incessant movement of material through the body, and parallel to this, a movement of *energy*. The normal condition requires that this stream of material shall be as pure and regular as possible ; that it shall make up for losses and re-establish the pitch or level. If this be so neither the mass nor the power of the human machine varies ; the man is in a state of *equilibrium*.

The function of the heart is all-important in this process. By its contraction or *systole* it acts as a force-pump, and, between its contractions, it expands its cavities and sucks in the blood returning by way of the lungs or the venae cavae ; and this dilatation is known as the *diastole*. In one of its cycles it accomplishes a good portion of the profound scavenging which the organism undergoes.

The systole of the two auricles take place *simultaneously*, and so with the systole of the two ventricles, the latter being more marked and more protracted than the former. The phases of the cardiac cycle, as regards their duration, are much as follows :

Auricular systole	..	..	18 per cent.
Ventricular systole	..	..	45 per cent.
General diastole	..	..	37 per cent.
Complete cycle	..	..	100

[The ventricle is the more important partner in this association. When beating at seventy-two per minute, its rhythm may be expressed thus :—

Ventricular systole .. 0·3 second ⎫ 0·8 second.
Ventricular diastole .. 0·5 second ⎭

Thus, in twenty-four hours the ventricle works for nine hours and rests for fifteen. If we remember that " work " in human occupations is not confined to the hours of labour,

but that energy must necessarily be expended also outside the factory gates, we see that Nature has arranged matters very much upon the principle of an eight hours working day. (Ed.)

It is the contraction of the ventricles which may be perceived by the touch, about the fifth intercostal space on the left-hand side ; this contraction constitutes the *heart-impulse ;* it may even be seen, in thin subjects, raising the wall of the chest in the region indicated, usually beneath the nipple. The clinician, who observes the subject from the outside, simply notes that the duration of the heart-beat represents a third or a fourth of the total period ; so that the ratio of the general diastole to the systole is 1 : 2 or 1 : 3. Or we may write the formula

$$\frac{D}{S} = 2·50 \text{ approx.}$$

This ratio is modified by fatigue ; *it tends to diminish.*

The weight of an adult heart is about 250 grammes (·55 lb. avoirdupois), and its rate of pulsation, during repose, is 65 to 70 per minute, a rate which increases progressively under the influence of muscular activity. The figure is 78 to 80 in women, and 80 to 90 in children.

The movement which the contractions of the heart impart to the mass of the blood is propagated along the arteries, where it is revealed by a pulsation of the walls of these vessels. It thus produces the *pulse*. If an artery be slightly compressed against an adjacent bone the beats of the pulse become plainly perceptible. The pulse is particularly well defined in the *radial*, *temporal*, and *femoral* arteries ; it may be felt best of all in the first of these.

The sounds produced by the heart are louder if the organ is *hypertrophied*, and weaker if it is the seat of degeneration. Auscultation also enables us, in cases of imperfect functioning of the valves, or *valvular insufficiency* (notably *mitral* insufficiency) to detect a *murmur* or *souffle*.

The function of the blood is essentially vital. Anything that arrests or impedes its flow, any compression of the channels of circulation, diminishes the nervous and muscular

forces, and may, in a relatively short period of time, endanger life itself.

An old experiment performed by Bishop Stenon [1] demonstrates this most important fact. He ligatured the great artery which supplies the hind legs of the dog. Hardly had a few minutes elapsed, when all power of locomotion disappeared ; the legs were rigid. The ligature was then removed, and the power of movement returned to the limbs. The nervous centres are even more sensitive to variations of the blood-supply. While compression of the fore-arm will leave the fingers active even after the lapse of half an hour, it is enough to press for 15 to 20 seconds on the carotid arteries which lead to the brain, and consciousness disappears.

The state of the circulation should always be made the object of a serious examination, particularly with reference to *violent exercise* in youth, or work performed by men who have been mutilated, by accident, or war-wounds, or operation.

XIII. **Functions of Relation.**—*Movement.*— But the highest function of man is *movement.* To be sure, the lower animals are similarly endowed with the power of movement ; indeed their movements display an incomparable agility and certainty. Still, their actions are purely instinctive ; I mean that the precision of these actions is complete or definitive. They are automatic, by virtue of heredity ; and as a rule they are *not subject to improvement.*

Man, on the contrary, calculates his results ; he trains and disciplines his movements, harmonising them in view of an end which he understands ; he is conscious of it. In him consciousness is never completely absent, even in the case of movements which are apparently automatic, such as walking ; consciousness *corrects* these movements as required.

The organs of movement comprise the *bones,* which make up the *skeleton,* and the *muscles,* which are as a whole assembled in *articulated systems,* levers which accomplish all the motor actions of animal life.

The energy which animates them is released by excitations

[1] Nicolas Stenon, Danish anatomist, promoted to a bishopric (1631-1687).

of the nervous system, which, assisted by the senses, above all by the senses of *sight* and *touch,* co-ordinate and direct the muscular contractions.

It must immediately be noted that the active organs are subject to a physiological law of the greatest importance, which I will call the *law of functional hegemony.* This ensures that every organ which is capable of contraction or of performing work may be the seat of nutritive and respiratory exchanges which are more intense than those occurring in any other part of the body. To the gland producing its secretion, the muscle contracting, the nerve-cell vibrating in response to sensation, an abundant flow sets in of the fluids of the organism, the blood and lymph ; the irrigation of contracted muscles, for example, increases to four or five times its normal volume ; through these organs, in the space of one minute, passes a weight of blood equal to about 85 per cent. of their own weight.[1] The nervous elements are stimulated, and produce the condition of *tonicity.* A silent labour is accomplished in the living cell or fibre, which makes possible, and develops, the function itself.

This excess of life at one point leads to an abatement elsewhere ; it is, above all, between the digestive organs and the organs of movement that the law of functional hegemony establishes that inequality so necessary to the performance of physiological work.

XIV. **The Osseous System.**—The skeleton constitutes the solid framework of the body ; the resistance of the bones is at least double that of pine-wood ; it increases until the threshold of old age is reached, but to a greater extent in man than in woman, for the bony tissue of the man is denser and his skeleton more massive. However, this resistance is modified by the mode of life and the kind of nutriment absorbed. Thus the bones of race-horses are denser than those of grass-fed horses. On the other hand, we encounter cases of a wholly peculiar and inherited fragility of the

[1] Chauveau and Kaufmann, *Comptes rendus Acad. Sciences,* Vol. CIV., p. 1352. 1887.

Frontal
Parietal
Malar
Temporal
Upper Maxillary
Lower Maxillary
Cervical Vertebrae
Acromion
Clavicle
Scapula
Sternum
Ribs
Humerus
Olecranon
Lumbar Vertebrae
Ulna
Ilium
Radius
Sacrum
Os Pubis
Carpus
Metacarpus
Phalanges
Ischium
Coccyx
Femur
Patella
Tibia
Tibia
Fibula
Fibula
Phalanges
Calcaneum
Tarsus
Metatarsus
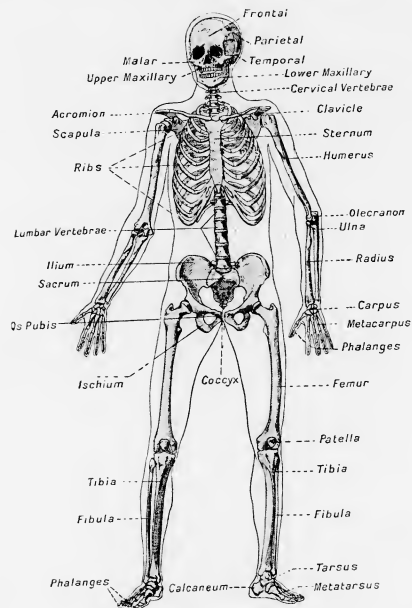
Fig. 10.—General Plan of the Human Skeleton.

skeleton ; this is known as *osteopsathyrosis* ; it is often betrayed by fractures of the femur and the humerus.[1]

[1] Davenport and Conard, *Proceed. Nat. Acad. Sciences*, Vol. I., p. 537, 1915 ; —Washington, *Hereditary Fragility of Bone* (Bull. No. 14 of the Eugenics Record Office, 1915).

Lastly, certain affections have their seat in the bony substance, whose solidity is thereby diminished.

It is from the food, conveyed by the blood, that the skeleton derives its formative elements, of which by far the most important are *phosphate* and *carbonate of lime*. The absence of mineral salts from the food, or mineral inanition, results in the softening and malformation of the bones, modifies their structure, and, in early youth, retards the progress of ossification.[1] The proportion of phosphate is diminished by 25 to 30 per cent. in infantile osteomalacia, and even further in rickets.[2]

Mineral inanition, if prolonged, is followed by serious nervous symptoms (Forster).

The natural arrangement of the various component portions of the skeleton is represented in Fig. 10. The different portions of the skeleton are all articulated, or jointed ; the surfaces which come into contact in the articulations are covered with *cartilage*, a smooth, elastic substance which reduces friction ; the *heads* of the articulations are in many cases enclosed in a capsule which contains *synovia*, a viscous and alkaline fluid which lubricates the surfaces of the articulations (example, the knee). The system of articulations is so devised throughout as to lend itself to all the requirements of movement.

XV. **The Muscular System.**—It is the muscles, however, which finally determine the positions of the osseous elements, while their fleshy masses give the human body its true plastic form. Before all, the muscles are the agents of movement, the *motive* elements of the body.

A muscle is a collection of *elastic fibres*, tightly enclosed within a thin, transparent envelope, and capable of progressive contraction. To the two ends of the muscle adhere two strong, coherent laminae or thongs : the *tendons*. A

[1] König. *Landw. Jahrb.*, p. 421, 1874 ;—H. Weiske, *Zeit. f. Biol.*, Vol. VII., pp. 179 and 333 ; Vol. X., p. 410, 1873-4 ;—J. Forster, *ibid.*, Vol. XII., p. 464, 1875.
[2] H. Brubacher, *Zeit. f. Biol.*, Vol. XXVIII., p. 517, 1890 ;—Gallinard and König, *C.R. Acad. Sc.*, Vol. CXL., p. 1,332, 1905.

D

familiar example of these terminal attachments is the *Achilles tendon* ; it lies in the lower portion of the calf, and is affixed to the bone of the heel, or *calcaneum.*

According to the portion of the body to be moved, and its organic adaptation, the muscles and tendons follow the same law of development as the skeleton,[1] and the osso-tendinous insertions acquire a remarkable strength, which renders possible the exertion of great muscular force.

The varying forms and arrangements displayed by the muscles in the different parts of the body are shown in Fig. 11. Their action, which is always conjoined, results in the production either of sustained efforts, which do not involve movement, but may be called static, or, on the other hand, of more or less rapid movements, and the speedy performance of work. This will be more fully explained later on.

The muscular system represents about 40 per cent. of the mass of the body, and it is in it that nutrition operates actively, with an intensity which is increased by work, and by external cold. One might almost say that it absorbs all the energy of the aliments consumed, and that the quantity of the latter should accordingly be regulated by the importance of the muscular system. Persons whose muscles are small, and persons suffering from obesity, have less occasion than others to consume large quantities of nutriment.

XVI. **The Nervous System.**—The co-ordination, which is almost invariably perfect, of the muscular contractions, is the work of the *nervous system,* the higher centres of which are the *spinal cord,* the *bulb* or *medulla oblongata,* the *cerebellum* and, most important of all, the *brain* proper. It fulfils its delicate functions in a wonderful manner, being at the same time a sensory system and a motor system, receiving sensations and sending forth orders relating to movement.

The entire surface of the body, the *skin,* which is the seat of the sense of *touch,* the *retina,* which receives impressions of luminosity, the *olfactory mucous membrane,* which is the

[1] See *Le Moteur Humain* for details of the very interesting influence of adaptation upon the organs of force and movement.

seat of the sense of smell, the mucous membrane of the tongue, in which the sense of *taste* is localised, and finally the
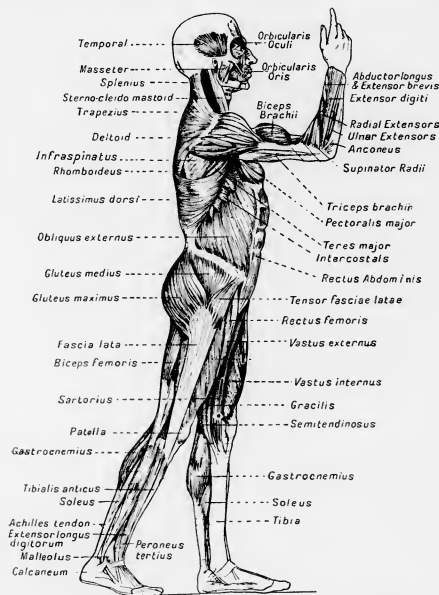
FIG. 11.—General Arrangement of the Muscles of the Human Body.

membrane of the inner ear, the *cochlea,* which vibrates under the impact of sound-waves, all receive from the nervous centres a number of *sensitive fibres,* which collect the multi-

tudinous impressions to which they are subject. These
sensitive fibres exist even in the depth of the *viscera* (heart,
stomach) and the muscles, and in the joints and tendons,
and it is by their means that the brain receives uninterrupted
messages as to the condition of the organism. Similarly,
there are also *motor* fibres, which, in the mixed nerves, are
associated with the first kind. These *mixed nerves* are in
a great majority.

The nervous element is known as a *neuron* : it is a cell
with numerous prolongations, so constituted as to conduct a
sensory impression or a motor impulse. Hence there are
sensory neurons and motor neurons, consisting, probably,
of fine granules bathed in a viscous matter, and set in motion
by all manner of influences.[1] The neurons, whose termina-
tions are in a *relation of contiguity*, form a chain known as a
reflex arc, from that which receives the impression to that
which reacts to a motor impulse. Let us consider the case
of a person who unexpectedly touches a heated body ; the
sensory filaments (Fig. 12), irritated by the scorching of
the skin, transmit a special vibration to the motor neuron,
which causes the muscle to contract.

Thus, by an actual reflexion of the sensation produced in
one nerve-cell, this sensation is followed by movement,
the more swiftly as the sensation is keener and the reflex
arc shorter. Generally speaking, nervous impulses are con-
veyed at the rate of about 120 *metres per second*. We know,
moreover, that these impulses display a preference for accus-
tomed paths, as these offer them a *minimum of resistance*. Let us
follow the progress of the nervous impulse set up by a burn,
so that we may at the same time obtain some idea of the
diversity of the mechanisms affected, and the marvellous
manner in which their action is controlled. From the irritated
skin the sensitive neuron conveys a special dolorific disturbance
to the *posterior horn* of the spinal cord, and there the filaments
of this neuron and those of the motor neuron in the anterior
or ventral horn enter into a relation which results in a release
of energy. In the diagram the spinal cord is supposed to

[1] Marinesco, *Comptes rendus Biologie*, 8 January, 1915.

be bisected horizontally, in order to show the grey cellular
region in which sensation, we know not how, is converted
into an order to this or that muscle to contract. It seems
admissible to us that all the neurons may vibrate in the same
manner, having all the same histological and chemical
character, and that their functions are sensory or motor
according to the
organs in which they
terminate.

XVII.—But what
we particularly wish-
ed to remark was
that this spinal reflex
arc is the shortest
possible. It is not
the only arc ; for the
disturbance follows a
fibre of the spinal
cord ascending to-
ward the brain, which,
when it reaches the
bulb or medulla
oblongata, finds a
number of further
relations available.
Here it may act upon
a second neuron which
proceeds directly to
the brain, after an

Fig. 12.—Paths followed by Nerve-Impulses, and
nervous Connections.

important relay in the *optic thalami*. The surface of the
brain, or the *cortex*, as it is called, contains motor cells of
a *pyramidal* form. One of these receives the vibration and
communicates it to its fellows. After a series of trans-
missions the disturbance attains a terminal centre in one of
the *striated bodies* (*corpora striata*), whence it returns to the
bulb and the spinal column.

The reflexion of the sensation therefore occurs in the

cerebral cortex, which is a *sensory* and *motor* zone, the seat of the general government of all the territories of the organism. The length of the reflex arc increases the time occupied by the reflexion. The *voluntary, conscious* action is therefore necessarily later in time than the involuntary, unconscious action of the withdrawal of the hand the moment it is burned. This latter movement is made, and the danger is averted; the act of will *follows* it ; but there is no need to repeat the movement of the hand ; the motor impulse is therefore checked, or *inhibited,* by an inhibitory cerebral neuron which intercepts it before it has passed the bulb or medulla oblongata (see dotted lines). *The phenomenon of consciousness and will appears therefore to be a process of sensory synthesis, which rectifies, orders, and adapts.* It is bound up with the very life of the nervous tissues, which are fed with a regular supply of blood, which brings with it the indispensable oxygen.

The manifestations of the intellect are rudimentary at birth, owing to a lack of sensations. In the child there is little skill of movement, because the cerebral cortex has not as yet assembled and combined, by means of its *associative neurons,* a sufficiency of the elements of synthesis by means of which *education* progresses. We must also mention the *cerebellum,* which co-ordinates the attitudes of the body and ensures equilibrium. The cortical cells of the cerebellum (Purkinje's cells) are as important as the pyramidal cells of the brain ; they receive the tactile, auditive, and visual sensations, and react on the muscular system by bulbo-spinal and even cerebral messages.

Thus the nervous system unites the surface of the body with a central axis which terminates in the mass of the brain. The connections of the neurons have often been compared to those of telegraph wires, which, starting from various points, report events, by successive relays, to a central office. The comparison is good, if we add that the messages received in this central office leave almost indelible records, for nervous tissue, more than any other living substance, retains a disposition to reproduce its past life, to react in an identical manner under the same stimulus, and to prolong its vibratory conditions

in time. This *organic memory* is the condition of the intellectual memory of which Shakespeare said that it was " the sentinel of the brain." Does it matter, after this, whether we are or are not exactly informed as to the exact manner in which sensations are transmitted, or the nature of *nervous energy,* or the part played by this or that nerve in the sensory-motor cycle ? It is enough to know that this inner world of so-called psychical forces reproduces the outer world, with which it communicates by means of the senses, and that its manifold echoes resound to the appeal of this outer world. This correspondence will explain some of the facts of *human psycho-physiology.*[1]

[1] Concerning the relations of the brain and the psychic self, see E. Becher, *Gehirn und Seele,* Heidelberg, 1911.

CHAPTER III

HUMAN PSYCHO-PHYSIOLOGY

XVIII. **The Development and the Endurance of the Body.**—The whole of the functions which we have been considering develop fairly rapidly with *age*, and the endurance of the human body is at its maximum between 25 and 40 years.

We find, in fact, that the skeleton completes the process of *ossification* and consolidation about the 20th year; not before. *Muscular energy* increases along the lines of a curve which rises rapidly from the 16th year, attaining its highest point between the 20th and 21st years. We may then conclude that the architecture of the body is sufficiently robust to resist the ordinary efforts of life as it manifests itself in young people of that age.

The *height*, together with the *weight*, has followed the same development, and, if the activities of the organism do not exceed the normal, the organs, internal and external, function without showing signs of overwork, so that a sort of physiological fitness, familiar to all, protects them from accidents and infectious germs. Under these conditions the development of the organism proceeds with moderate rapidity and in full security.

From the 50th year the process is reversed; there is a comparatively slow descent until the 60th year; sometimes the process is hardly perceptible. Thus from the 20th to the 60th year man displays his maximum capacity for work and exercises all his faculties most fully, provided he is able to avoid excesses, and does not suffer from any *predisposing taint* (tuberculosis, syphilis, hereditary alcoholism). But

40

about the fiftieth year "something like an ageing of the whole being occurs. . . . This crisis, which gives the observer the impression of a *crisis of age*, commences, most frequently, by digestive disturbances." [1] It also reveals itself by a general lassitude, a weakening of the will, and a retardation of the processes of nutrition.

This *critical age* corresponds to a period of a few months at most, and leaves no lasting disturbance. Childhood also has its critical period : that of the *anaemia of growth*, which occurs between the 5th and 7th years; [2] the body grows taller and thinner; the blood is less rich; the energies diminish. The child must be guarded against all excessive effort, in order that the organs may develop in a normal manner. *Adolescence*, which commences about the 16th year, and *youth*, which continues to the 40th year, form the age of power, bodily and mental; they create the works which the *virile age* ripens and reinforces. Woman completes her development at an earlier age; according to the climate, she attains the age of puberty between 13 and 15 years, while her height and her strength are fully developed by her 19th year.

Her strength is *half* that of man, and it is not exerted so rapidly. At 50 years old age sets in with the *menopause*, the cessation of the menstrual function. One may therefore estimate the period of full physical activity to be 40 years in the case of the man, and 30 years in that of the woman.

XIX. **Psychical or Mental Activity.**—Psychical activity follows almost the same lines of development, except that it survives physical activity, and sometimes resists the effects of a very advanced age. Nervous excitability is greater in the child than in the adult; childhood is the period of keen sensations and excess of movement; the nervous system betrays its predominance over the other systems; one sees its filaments under the skin; the senses reach out for education; experience is in process of formation, and the moment is propitious to impose *selection* and *direction* upon it. Intel-

[1] M. de Fleury, *Tribune médicale*, p. 69 ; 1910.
[2] L. Furst, *Das Kind und seine Pflege*, Leipzig, 1877 (2nd ed.).

lectual labour is for many years a *work of absorption*. At the age of 25 years in man, and 21 in woman, it is transformed into a *work of restitution*, which may reveal itself, between the ages of 40 and 50, by the loftiest creations of the mind.

The *creative faculty*, which combines and co-ordinates sensations, is chiefly the appanage of man ; the other sex is characterised by the survival and reinforcement of those sensations which predispose it to create works of *imagination* or *sentiment*, rather than works which call for hard thinking and determined application. The same remarks apply to *attention*, which requires that certain sensations among all the sensations of our life shall by preference occupy the field of consciousness, and is therefore, by this fact alone, an attribute of the male organisation, which is characterised by motor impulses and will-power. The cerebral cortex, on which the entire muscula-ture is, so to speak, *projected*, and which, in man, fulfils the motor functions more fully, should provide the explanation of these sexual differences, in which some have wrongly per-ceived a difference of intellectual level.

Möbius [1] has vigorously maintained this theory of *feminine inferiority*, which is, in his opinion, caused by the *small mass of the brain, the keen sensibility of woman, and the close approxi-mation of her instincts to those of the animal.*

It is true that the cerebral mass of the male brain is larger than that of the female brain. Its weight is estimated at birth as 400 grammes, as against 380 grammes.[2] The schoolboy has a larger head than the schoolgirl, even at or about the age of 11, when girls are, generally, speaking, further developed than boys.[3] In the adult, the man's brain attains the average weight of 1,370 grammes, and the woman's brain the average weight of 1,223 grammes, and this difference of 147 grammes is observed in persons of the same weight but of opposite sex.[4]

[1] Möbius, *Über den physiol. Schwachsinn des Weibes* ; Halle, 1912.
[2] E. Handmann, *Arch. f. Anat. u. Phys., Anat. Abt.*, p. 1, 1906.
[3] Beyerthal, *Jahrb. u. die Schülarztliche Tätigkeit an den Hilfsklassen Städt. Volkschule in Worms, Schuljahr*, 1904-5. Rose, *Arch. f. Rassen u. Gesel. Biol.*, Vol. II., p. 689 ; Vol. III., p. 42, 1905-6.
[4] Félix Marchand, *Biol. Centralblatt*, Vol. XXII., p. 12, 1902.

But this is of no significance, for greater differences often occur between individuals of the same sex, which bear no rela-tion to the intellectual capacities. Precious ideas may exist in a small head, and the heaviest brain will not always prevent imbecility.

Thus, despite the proofs which he strives to furnish of the inferiority of woman, and the ridicule which he throws upon " the unnatural effort of feminism," Möbius appears to me to be the victim of a confusion of ideas. There is not, between man and woman, a difference of degree in respect of cerebral power, or intellect, or the *quantity of psychical energy* pro-duced ; there is only a question of *quality* ; the modes of intellectual labour are not identical. In the case of the woman sensibility holds the first place ; it is imposed upon her by habit and by heredity. In man, on the contrary, abstract thought and reason come first ; and by virtue of this very quality of abstractness a comparative independence of the motor functions is established in respect of external actions ; and it is this independence which is expressed by the word *will*.

Accordingly, the development of the mind takes place upon two frequently distinct planes. I readily admit that the feminists confuse the two planes, at all events physio-logically speaking. But " feminism " finds its profoundest justification in its social applications ; I mean, in life such as it has been made by the usages of the modern world, and its economic laws and conditions.

To return to the human brain : it seems difficult to derive any information from its weight, its convolutions, and its archi-tecture. Neither does the examination of this organ enable us to form any conclusions as to race ; its average weight is the same in the Australians, the Hindus, the Chinese, the Japanese, and the Malays as in the European. The brain of the negro, however, is less massive and less dense.[1] But there is no real relation between quantity and quality, between mechanical and psychical factors. Races, like individuals,

[1] Kohlbrugge, *Zeit. f. Morphol. u. Anthrop.*, Vol. XL., p. 596 ;—*Verhandl. d. könike Ak. v. Wetensch te Amsterdam*, Vol. XV., p. 1, 1909.

and like the two sexes, do not reveal any visible cerebral index of intellectual inequality.

XX. Old Age.—The development of the functions modifies its pace during age, that is, from the fiftieth or sixtieth year, according to sex. All the organs tend to become atrophied; the strength, weight, and height *diminish*; the body, little by little, becomes emaciated and anaemic (*senile anaemia*). From the seventieth year these phenomena undergo acceleration; the skeleton becomes fragile, and less dense, above all in the bones of the lower limbs (*fragilitas vitrea*), which lose a portion of their calcareous constituents. These gradually calcify the vascular organs, rendering them less elastic; arteriosclerosis makes its appearance, with its formidable sequelae; the circulation of the blood encounters an increased resistance, which causes a *hypertrophy of the heart,* and retards the nutritive exchanges. According to the dictum of Cazalis, " a man is as old as his arteries." [1]

The action of the lungs is impeded, and becomes less elastic, while emphysema is often observed. Respiration is neither frequent nor profound; there is a retardation of the vital processes. Those portions of the lung which lie between the heart and the wall of the chest lose their elasticity, so that the heart becomes united to this wall. " Without the existence of adhesions," says Pierre Delbet, " this cardio-thoracic solidarity causes, in a certain sense, a functional *symphysis*." [2] Hence the shortness of breath which accompanies physical effort in the majority of men who have passed their fiftieth year.

As for the locomotive organs, the muscles become pale and emaciated; the contractile tissue is less abundant, and its structure is impaired; it no longer responds to its function, especially as the articulations themselves are stiff and painful.

The entire *nervous system,* moreover, suffers depreciation; the cell, the centre of energy, and the controller of action,

[1] Consult Demange, *Étude sur la veillesse*; Alcan, 1886 ;—S. Minot, *The Problem of Age, Growth, and Death*, London, 1908 ;—H. Ribbert, *Der Tod aus alter schwäche,* Bonn, 1908 ;—E. Metschnikoff, *Essais optimistes,* Paris, 1907.

[2] Pierre Delbet, *C.R.*, Vol. CLX., p. 402 ; 29 March, 1915.

is invaded by waste tissue which has no energetic properties. The brain is atrophied, notably in the frontal lobe; this atrophy was observed by Hansemann [1] in the historian Mommsen (86 years), the chemist Bunsen (88), and the painter Menzel (89); but it is barely perceptible in the *cerebellum*.[2] From this it results that the *equilibrium* of the body is maintained, although the movements are more deliberate. The nervous energy is unequal to voluntary stimulation; hence a sort of vacillation, the *tremulousness* of age, and the inability to sustain a great and prolonged physical effort.

As for the *cause,* sole or multiple, natural or accidental, of age, it has formed the subject of a whole series of studies, the consideration of which would lie outside our programme.[3] But in a word we may say that old age is a phase—not the termination—of cellular transformation; a phase which continues for a longer or shorter period, according to the quantity of toxic products resulting from organic life. Everything which diminishes this poisoning process, temperance in the matter of diet above all, must be regarded as a factor of longevity.

XXI. Human Aptitudes.—1. *Physical aptitudes.*—The general form of the body is, geometrically speaking, as little cumbersome as possible in the case of so complicated a machine. The *trunk* encloses the organs capable of maintaining movement, and of providing the muscles with energy. It is interesting to observe, in this connection, that persons of *moderate stature* are the most robust. If we compare the *height when seated* with the *total stature*, we obtain a *thoracic coefficient of* 0.54. This ratio is slightly lower—0.53—in tall persons, and in most women. A lower coefficient than 0.52 is the mark of a rather feeble constitution. The importance of the seated height is connected with the physiological function of the thorax, and the semi-fixity of its dimensions. It includes the

[1] Hansemann, *Bibliot. Med.*, Abhard. II., Anat, part 5.

[2] A. Léri, *Le Cerveau sénile*, Lille, 1906 ;—Anglade ard Calmettes, *Nour. Iconogr. de la Salpêtrière*, p. 357, 1907.

[3] See A. Dastre, *La Vie et la Mort,* p. 314, Paris, 1907 ;—Muhlmann, *Das Alt. u. d. Physiol. Tod,* Jena, 1910 ;—Metchnikoff, *loc. cit.*

axis of the body, the vertical column, from which the heart and the lungs are to a certain extent suspended. It is more fully developed in man than in woman ; for man, by reason of his greater muscular power, has need of an intense respiratory activity, a great absorption of air ; while in woman there is a marked predominance of the vegetative functions. The average man weighs about 65 kilogrammes (10 stones 3 lbs.) for a height of 165 centimetres (5ft. 5in.). I will give the name of *morphological coefficient* to the ratio between these two quantities, which is $\frac{65}{165} = 0.394$; it should not fall below 0.360, or the resistance of the organism may be compromised. These two coefficients, the thoracic and the morphological, complete one another, and their indications are almost invariably in concordance. The human body spreads outward as do the columns observed in ancient monuments ; it is strongly reinforced in the region of the pelvis. According to the wisdom of the ancients, the strength of a man resided in his loins ; but an exaggerated development of the iliac bones hampers movement, giving rise to a rotatory gait. Thus nomadic, drifting peoples possess a comparatively narrow pelvis, while in the case of heavy-weight athletes the hips are wide and well provided with muscles.

XXII.—Dynamic activities (manual and other physical labour, sports, games, etc.) favour the growth or the refinement of the body ; market porters, waggoners, draymen, dock labourers, are often massively built ; dancers, runners, and fencers are slender, almost thin. The bearing of burdens, or, in cripples, the wearing of artificial limbs, in the long run modifies the form and the strength of the limbs ; walking eventually causes the foot to become permanently flatter and longer, while the hand is equally affected by the handling of heavy tools (hammers, pick-axes, spades, etc.) ; the spinal column becomes curved by the bearing of burdens (as in peasants, porters, and occasionally infantrymen) ; under continuous pressure it undergoes a thickening which slightly reduces its length—that is, the stature. *Physical education*, above all in childhood, should aim at a harmonious develop-

ment of the framework of the body, and at making it straight again should it become at all misshapen. The orthopædic surgeon will take care that artificial appliances are perfectly adjusted, and that no friction occurs.

Physically speaking, the proportions of the limbs are not without effect upon professional aptitudes ; *long* limbs are adapted to ample but deliberate movements, while *short* limbs denote *rapidity* of movement. Thus the woodcutter, the blacksmith, and the sawyer develop more power, and produce a greater effect. if the implement they wield has a long arm behind it. The formation of the body is often, in this connection, a guide to the choice of workers fitted for this or that form of labour ; but these indications are far from absolute in character, for *adaptation* is a factor of the greatest importance ; the fencer Kirschoffer did wonders in spite of his small stature, which placed him at a disadvantage and exhausted his strength.

In general, however, men are organised and adapted to work in a certain fashion, for in this case their labour is more economical. They might be divided into types, according to the physiological function which they display most prominently, and which appears to control all the rest. One of these types is the *digestive* type ; men of this type eat very largely, and work slowly, but they can labour for long periods ; if they have well-proportioned limbs they may become good runners. The runners of the East, the *rekkas*, cover very great distances, with a long, rapid stride. Such men are capable of a great output when carrying small burdens for long periods (Fig. 13).

A second type is the muscular type. Men of this category are capable of exerting great energy, though never for a very long time ; but the musculature of this type may be harmoniously developed upon a perfectly symmetrical body, constituting a perfect morphological expression. In such cases the man is powerful and supple, capable of continued activity : he represents the maximum of energy in the minimum of mass. The accomplished athlete provides an example of this type (Fig. 14).

A third type, described as respiratory, possesses the advantage of being capable of sustaining a comparatively great effort

FIG. 13.—Digestive Type (Thooris).   FIG. 14.—Muscular Type.

for a long period ; the thoracic cage is preponderant, and the shoulders are largely developed (Fig. 15).

Lastly, we must certainly distinguish a *nervous* type, which, owing to the celerity with which its muscles contract, works

with economy, is, by reason of this very speed, capable of exerting great effort, and, owing to its temperament, is able to resist the onslaughts of fatigue (Fig. 16).

FIG. 15.—Respiratory Type.   FIG. 16.—Cerebral or nervous Type.

Sigaud, who has defined various types of humanity, especially from the standpoint of morbid development,[1] has paid

[1] C. Sigaud, *Traité de la digestion*, Vol. II., Paris, 1908 ; *La Forme humaine*, Vol. I., p. 32, 1914.

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FIG. 13.—Digestive Type (Theorist).   FIG. 14.—Muscular Type.

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particular attention to the development of the nervous and cerebral systems, and calls our attention to the cerebral type (Fig. 16), which we should rather regard as the nervous type with psychical predominance. In Figs. 13 to 16 Thooris has collected representations of the four types which we have just described. These photographs are highly expressive; but it should be added that they are selected; that in reality the average man approximates to one of these types, without displaying very definite characteristics; and, in a word, that we should not disregard the marvellous resources of *equilibrium* and *training*, which the organism is able to draw upon. "Practice can do anything," taught the Greek philosopher Periander, twenty-five centuries ago. It is none the less true that the distinctions between the four types are physiologically of the greatest interest, for they indicate the predominant organic function, and what the latter demands for its normal exercise. For example, to give a nervous type the same regimen as to labour and alimentation as the digestive type would be absurd; the man would not put forth his maximum of useful effort, and his health might suffer from the experiment. The methods to be observed, in the matter of physical culture, will be different and appropriate for each of these functional and energetic types.

XXIII.—2. *Psychical Aptitudes.*—Let us, on the other hand, consider the *psychological* qualities of the individual. These are the reflection of his physiological condition; the problem has even been simplified to the extent of attributing them to a special structure of the brain. But very little survives of the speculations which substituted the cerebral cortex for the *cranial protuberances* of the famous phrenologist Gall (1758–1828). To-day the sensori-motor surface of the brain has been sufficiently analysed by physiological experiment to enable us to deduce certain doctrines therefrom. To begin with, we may refer to that already formulated (§ XVII.): namely, that the cells of the grey cortical layer belong to sensory or motor neurons, or to the neurons of association; certain among them are said to fulfil a function of *inhibition*,

and there are some which, being stimulated from without and under special conditions—by a sound, a shock, or a light—reinforce the motor reaction, and the exercise of muscular force.[1] Then it has been noted that the stimulation of the cortex produces movements exhibiting a character of order and co-ordination; while the suppression of a portion of this cortex renders certain of these movements, and certain sensations, impossible. For example, a dog upon which this operation has been performed is able to walk and to leap, but he can no longer hold a bone and gnaw it.[2]

This method of investigation has enabled the physiologists to distinguish *cortical territories*, and to determine actual "cerebral localisations"[3]: that of the *tactile sense*, the most extensive, covering the Rolandic convolutions, with the ascending frontal and parietal convolutions; that of the *acoustic sense*, situated in the temporal region; that of the *visual sense*, situated in the occipital lobe; and that of articulate language, known as *Broca's centre* (1861), whose existence was too positively contested by Marie,[4] but was accepted by Marinesco, and which is supposed to occupy the third left-hand frontal convolution.

The ablation of the *parietal cortex* of the dog deprives it of the ability to ascend or descend a staircase, or to "give its paw." Here we have the localisation of a function of association and co-ordination of the elementary mental processes. A lesion of this lobe, in the monkey[5] or in man, renders the character *impulsive* and *violent*. Its moderating action

[1] This is the phenomenon of *Bahnung*, or the *nervous acceleration* of the German writers. (See *Le Moteur Humain*, p. 343.)

[2] Ferrier, *Les Fonctions du cerveau*, Paris, 1878;—Rosenfeld, *Die Physiologie des Grosshirns*, Leipzig, 1913.

[3] J. Demoor, *Les Centres sensitivo-moteurs*, Brussels, 1899;—Von Monakow, *Neue Gesichtsp. in d. Frage nach d. Lokal in Grosgehirn*, Wiesbaden, 1911.

[4] Marie, *Semaine med.*, May, 1906;—Marinesco, *Rev. Gen. Sc.*, p. 826, 1910.

[5] Bianchi, *The Brain*, Vol. XVIII., p. 497, 1895.

is obvious ; with it disappears the mechanism of the direction and control of the reflexes ; fewer neurons are brought into play, the conscience becomes enfeebled, and the duration of the reflexes is diminished by about one-fourth, owing to the lack of the internal activity which harmonises them.[1] Brodmann, moreover, has noted, in the human brain, an exaggerated development of the lower portion of the frontal lobe. Physiologists are therefore strongly inclined to see in this tract the localisation of *psychical activity*.[2] " Beat, friend, upon thy brow ; 'tis there that genius dwells," says the poet. But as a matter of fact, we cannot admit that the neurons of the frontal region possess more than a superior function of control and moderation, a function which is developed by habit, which creates strength of will, coolness, and apparent moral insensibility.

Certain writers attach no less importance to the parietal convolutions, because they are highly developed in the case of men of superior capacities (notably in Kant and Gauss),[3] and because they are greatly reduced in the case of uneducated and backward persons, and in negroes.

Now this is not very decisive, for whereas Gauss's brain, for example, displayed a predominant frontal lobe, it was also discovered that it contained a profusion of fine convolutions, which some regarded as indications of mathematical genius.

So far we must admit that no certain information of the localisation of the psychical faculties has resulted from the study of the brain, still less from that of the skull.

In Fig. 17 we give a diagram of cerebral localisations, in accordance with recent ideas. If the reader will remember that the nervous fibres of the spinal cord cross from side to side in the region of the bulb, he will understand the reason of the

[1] Fano and Libertini, *Arch. ital. Biol.*, Vol. XXIV., p. 438 ;—Oddi, *ibid.*, Vol. XXIV., p. 360, 1895.

[2] K. Brodmann, *Vergl. Lokalizations lehre d. Grossh.*, Leipzig, 1909;—*Verhandl. d. Anat. Gesellsch.*, April, 1912.

[3] A German philosopher and a German mathematician.

correspondence between the left cerebral hemisphere and the right side of the body, and *vice versa*.

XXIV.   **The Personal Equation.**—After all, the brain should be studied in connection with its physiological properties, and the nervous processes themselves. In this connection we know that reflexes do not occur with uniform rapidity in the case of every individual. The most rapid reflexes occupy four
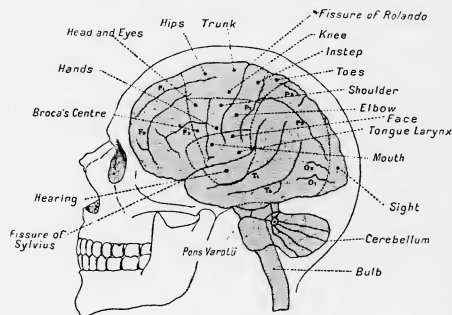
Fig. 17.—Diagram of Cerebral Localisations.

to five hundredths of a second ; but their duration is modified by age ; long in the new-born child, it is greatly diminished in the adult and as a result of practice. On the other hand, it is increased by certain lesions of the nervous centres, principally those of the cortex. The name of *personal equation* has been given to the period of time which divides the moment at which we perceive a tactile, visual, or auditive sensation, and the moment when we react by a movement. Many phenomena occur between these two moments, which cannot be analysed in this brief survey of the dynamics of the nervous

system. We will simply remark that the normal adult possesses a personal equation, the values of which are as follows :

Tactile reaction	.. ..	0·14 of a second.
Auditive reaction	.. ..	0·15 ,,
Visual reaction	.. ..	0·19 ,,

To measure it, we may conveniently employ the stimulation of light. An electric current illuminates an incandescent lamp, now red, now blue, and at the same time releases a
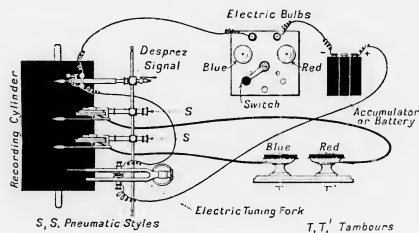
FIG. 18.—Device for Measuring the Personal Equation.

Desprez signal (Fig. 18). The subject perceives the sensation of colour, and reacts by pressing one finger on the red or the blue key, which actuates the diaphragm of a simple transmitting device. The time is recorded in hundredths of a second.

The distance between the records traced by the Desprez signal and the styles of the transmitting tambours gives the duration of the reaction, which in this particular instance comprises an additional element, that of choice between the two finger-plates.[1]

Observation has definitely demonstrated that there are persons whose equation is long, and others whose equation is

[1] For other types of apparatus see Toulouse and Piéron, *Technique de Psychologie expérimentale*, Vol. II., 2nd ed. Paris, 1911.

short ; that is, they may be divided into *quick* and *slow* subjects. We have here an important qualificative classification, intrinsic in the individual, based upon his proper reactional condition, into which enter the effects of heredity and education. A man whose reactions are slow and whose sensations are not acute is not fitted to perform work demanding dexterity and attention. We shall see later on that the personal equation may be very simply determined (see § LXVI.). The *voluntary movements*, which are ordained *directly* by the brain, without external stimulation, are evidently more rapidly produced ; the equation may fall as low as ·07 of a second.

As for the purely *intellectual* qualities, they are the result of disciplined and methodical cerebral training, by instruction, superimposed upon hereditary influences. They are revealed more particularly by *integrity of mind, judgement*, and *attention*, which depend far more upon the will than upon sensitiveness. An experience of men enables one to estimate, without any serious error, the degree of intelligence possessed by a man, or the balance of his mental powers. But it is highly desirable that these should be estimated on entering the school or the workshop ; that a sort of *psychometric record* should be kept, of a faithful and accurate character. Later on this would provide useful information, which could be supplemented by means of discreet and skilful inquiries made of friends and relatives. For to rely, when making a selection of persons, on the impression received upon seeing them, and hearing them speak, is to run the risk of serious errors. Very often the appearance of a man tells nothing, and the subject of conversation, and the circumstances, are unfavourable to any display of his qualities. In matters of knowledge and behaviour, and of physical and intellectual capacity, long and methodical experience must be the only guide.[1]

Neither must it be forgotten that the psychical qualities are for the most part hereditary, and are transmitted, as are physiological defects and mental weaknesses, through several generations. It is the same with the intellectual habits

[1] In this connection see Mrs. Gilbreth, *The Psychology of Management*, New York, 1914 (Sturgis and Walton).

acquired by exercise. Humphrey Davy observed that this was the reason why Moses forbade the Hebrews to wed with idolaters.[1] It is a reason which loses none of its force when applied to the conditions of civilisation and culture.

And all these elements, physiological and psychological, which we have considered in isolated groups, must in reality be grouped in the light of their mutual relations, which are not merely parallel, but intimate and profound. These *psycho-physiological* relations are of interest to the employer, the factory manager, the physician, and the legislator.

XXV. **Psycho-physiological Relations.**—*Pleasure.*—We have stated that every external impression is the origin of a sensation. This sensation may remain latent, being neutralised by others, and may later on release a reflex; it is none the less true that there is a diminution or augmentation of nervous energy at the point which has been affected.

Sensation may, and frequently does, give rise to *manifest emotional activities*, to *pain* or *pleasure.*[2] We are all familiar with instances of *repressed* emotion; and men have been known to fall dead of a "broken heart," although there was nothing to betray their increasing grief. The neutralisation of the emotions is a function of the cerebral cortex, acting through the optic thalami or the bulb (see Fig. 12); but it is dependent upon the sound condition of the digestive organs and the heart, which are innervated by these centres.[3] Above all, we must not lose sight of the fact that repressed emotions may in a greater or less degree modify the neuro-muscular energy. In any case they reveal a trained *will.*

But the absence of visible indications of reflexes is sometimes connected with a condition of intellectual decay. In such cases it is necessary to make sure, by means of a cautious analysis, whether the emotive system is intact. In this connection excess is preferable to deficiency, for it must be

[1] Humphrey Davy, *The Last Days of a Philosopher.*
[2] See Bechterev, *Psychologie objective*, Paris, Alcan, 1914.
[3] Brissaud, *Leçons à la Salpêtrière*, Vol. I., Paris, 1895;—Bechterev and Mislavsky, *Soc. neurol. et Psych.*, Kazan, 1893.

remembered that the intelligence is directly dependent upon sensibility.

The man who is experiencing an emotion behaves differently, accordingly as it is a cheerful or a depressing emotion.

The emotions of pleasure and joy increase the tonicity of the voluntary muscles, and incline them to effort; they exert an inhibitive effect upon painful sensations, and, to a certain extent, cause fatigue to be overlooked. These facts have been known from antiquity :

Molliter austerum studio fallente laborem (Horace).

The respiration becomes accelerated, and maintains the energies; the heart increases the amplitude of its beats, and the circulation of the blood is stimulated on the surface; there is a cutaneous vaso-dilatation. Everything which may contribute to these phenomena of nervous and cardiac *tonicity* should be regarded as desirable : rewards, prizes, competitions, decorations, and moral advantages; they are not unwelcome at any age; it is a matter of receiving one's deserts, which we are naturally inclined to make manifest. Sports and amusements act as veritable tonics when they are employed without excess; they are as necessary to the workshop as to the school; a recreation-room or a playground is a factor of good work, the cost of which is negligible in view of its utility.

Not only does the degree of pleasure merit attention, but also its selection and its appropriation, having regard to age, sex, habits, and degrees of intelligence.

Sensations of a joyful nature do more than stimulate activity, they favour the vital processes; they facilitate the digestion of food, and add to the abundance and efficacy of the digestive secretions. Moreover, in the cycle of organic repair we find that cellular renovation is more rapidly effected. Soldiers who have performed some distinguished action recover quickly from their wounds. " Joyous men," said old Paré,[1] " always recover."

XXVI. **Pain.**—The phenomena due to *grief* and *pain* are absolutely the reverse of those we have been considering.

[1] Ambroise Paré, the great French surgeon, born at Laval (1517-1590).

They are characterised by a disturbance of the muscular inner-vation, an inhibition which makes one feel " as if one's arms and legs were broken." The respiration is embarrassed, dyspnœic ; the movements of the heart are of reduced amplitude ; the cutaneous circulation is scanty ; there is a peripheral vaso-constriction.

The cardiac manifestations are strongly marked, and often serious ; notably in cases of *fear* and *anger*. The surgeon Desault, during the Revolution, observed that affections of the heart and aneurisms were far more common during that terrible period. The number of aged persons who have died during the present war is very great. This may in part be explained by the narration of the atrocities committed, and the unheard-of employment of new weapons of warfare : aero-planes, dirigibles, incendiary bombs, submarines, asphyxiating gases, etc.

Violent emotions cause a powerful excitation of the bulb, and give rise either to *palpitations* or to *syncope*, with all its consequences. For in the bulb originates one of the most important nerves of the organism : the *vagus* or *pneumogastric* nerve, whose branches are distributed over the head and neck, and through the thorax and the abdomen. It arrests the heart, which is completely filled with blood, in the *diastolic phase*. By this a blow is immediately struck at the vitality of the brain ; the consciousness disappears ; the organs become insensible, and the muscles relax. Cardiac syncope is thus complicated by cerebral anaemia and physical depres-sion.

Having regard to the importance of the circulation of blood through the tissues it will be understood that any cause which impedes it compromises human life and energy. The relation between the heart and the brain is clearly established, and it is the most active and essential relation of the organism. It plays its part in anger, as in discouragement and fear, engender-ing disorders of locomotion, lack of co-ordination in the movements, and, in some cases, an actual paralysis of the limbs ; it exerts an inhibitory effect upon the glandular and digestive secretions, but favours the secretion of tears, and

also increases the peristaltic movements of the intestines and the contractions of the bladder. Experiment has demon-strated that such emotions excite the Rolandic area of the cerebral cortex.[1]

Boredom, *ennui*, mental discontent, should also be included in the category of painful sensations. It diminishes the tonicity of the muscles, which contract less swiftly and with less amplitude, and develop less power.[2] It causes a slight anaemia of the brain, which renders the latter incapable of good and regular work ; finally, it dilates the blood-vessels, producing a condition of stasis in the latter, which is revealed by a tendency to yawn. An agreeable emotion will immedi-ately abolish these disagreeable phenomena.

As for *pain*, it has no effect upon the brain excepting through the relation between the brain and the heart, for the organ of thought is in itself *not subject to pain ;* one may touch the brain or press the heart when these organs are uncovered, but there will be no perception of pain. Once again, poetry is in the wrong.

But the enveloping membranes of the brain, above all the *dura mater,* may become painful ; it is only these tissues which are affected by disagreeable sensations, the result being headache.[3] But pure mental pain is the work of the imagination ; it draws its sustenance from the seat of the memory, and arouses all the echoes of the past. One might almost say, with Richet, that it is " a function of the intelli-gence," [4] for it is less keen in simple-minded persons, and does not persist, does not " keep vigil " ; it is almost unknown in idiots, lunatics, and the feeble-minded.

Physical or psychical pain is in proportion to our sensibility, to the delicacy of our senses, to the intensity of excitation :

[1] Bechterev and Mislavsky, *Arch. f. Anat. u. Physiol.*, Suppl. p. 243, 1889 ; p. 380, 1891.—Bochefontaine, *Arch. de Physiol.*, pp. 140-172, 1876.—Bechterev, *Die functionen d. Nervencentra*, Jena, 1908-11.

[2] W. C. Lombard, *Journ. of Physiol.*, Vol. XIII., p. 1, 1892 ;—Jules Amar, *Le Moteur Humain*, p. 294

[3] Lennander, *Mitteilungen aus d. Grenzgb. d. Med. u. Chir.*, Vol. X., pp. 38-104 and 164-202 ; Vol. XIII., pp. 303-372 ; 1902 and 1904.

[4] Ch. Richet, article on *Douleur*, in the *Dictionn. de Physiol.*, Vol. V., p. 173.

habit lessens its effects. The child who is accustomed to having blows rained upon him, the pupil or apprentice who is constantly subjected to abuse and insult, no longer feels more than an indifferent amount of pain. The nervous element whose energy has been exhausted by pain finds it difficult to recover its power of reaction, its irritability, especially if it has been overcharged by very powerful and painful excitation.

The domain of pain is the most extensive of all because it embraces the *entire tactile area*. And it is no less extensive in time, for pain survives in the consciousness by means of a sort of vibration which becomes damped but slowly, and on the first opportunity its amplitude is again increased. This survival makes pain a vigilant guide, enabling us to avoid *evil* in all its aspects ; it makes it a factor of teaching and discipline. " Painful emotions," writes Ch. Richet (*loc. cit.*, p. 191), " move us profoundly, remaining fixed in the memory, when they direct our conduct. The whole intellectual, moral, and social development of humanity is the result of painful emotion which has to be avoided. The knowledge of things interests us only because it constitutes a means of fighting pain more effectually. Bloodless science does not stir us ; it is not a guide ; it is not a motive of action ; while pain is the great motive force of the life of sentient beings."

It is plain, however, that in order to be salutary, " in order to be the mainspring of our actions " (Voltaire), pain must respect the order and integrity of the economy ; it must not give rise to any profound disturbance ; it must threaten, without irremediably injuring. Only then does it become a factor of energy.

XXVII. **The Psycho-physical Law.**—But that which in any sensation dominates our faculty of perception, whether the sensation be tactile, sonorous, or visual, is the *degree of that sensation*; in other words, it is the *relation* which our consciousness has to establish between the sensation and the excitation which has given rise to it.

Everyday experience teaches us that one person will appreciate a minimum *difference of weight* better than another ; but

that the *same difference* may be unperceived when the weight itself is increased.

F. Weber noted that in order to be *definitely perceptible* the difference between the two weights should represent a constant fraction, equal to 1-17th of either of them.[1] But this is not correct ; the difference need not be increased as rapidly as the weights ; in other words, *the intensity of sensation progresses less rapidly than the intensity of stimulation*, the curve of sensation lying always beneath the curve of stimulation. This mode of progression is known as *logarithmic ;* it was recognised by Jacques Bernouilli, and more clearly defined by Laplace,[2] in connection with the *mental good* experienced when there has been an increase of *material good*.

Various writers have observed that this is, in general, the relation which exists between sensations and stimulations. For example, according to Nicati[3] sensations of luminosity are in a *logarithmic* relation to the intensity of the visible sources of light.

But as a matter of fact the *psycho-physical law* is correct only within very narrow limits as regards the intensity of excitation, and Fechner was wrong—doubly wrong—in calling it a " formula of psychological measurement," and in allowing it to be described as " Fechner's Law," [4] for it is devoid of real theoretical or practical value. " It will remain," in the words of James, " like a fossil in the history of psychology." [5]

Yet there is, there must be, a law of this kind ; but it must be more complex, and *time* should figure in it, for sensation depends at once upon the intensity and the duration of the excitation. By virtue of its very nature it is *perfectible*, in the sense that an *individual constant* must be introduced into the expression of this psycho-physical law. We shall not attempt,

[1] E. Weber, *Wagner's Handwört.*, Vol. III., 2nd part, p. 481, 1846.

[2] Jacques Bernouilli, *Ars Conjectandi*, French trans. by Vastel, p. 61 ; Paris, 1801 ; Laplace, *Œuvres* (authorized ed.), Vol. VII., p. 441, 1829.

[3] Nicati, *La psychologie naturelle*, pp. 165, 225, Paris, 1898.

[4] Fechner, *Elemente der Psychophysik*, Leipzig, 1800.

[5] W. James, *Principles of Psychology*, Vol. I., p. 549, 1901.

in a volume dealing with the elements of our subject, to go deeply into a particularly difficult problem of a mathematical nature.

XXVIII. Conclusion.—We may conclude, in a general manner, that the body and the mind, in their development, are obedient, on the one hand, to inevitable *hereditary* influences ; those influences of which we might say, in the words of the old French proverb, *Chassez le naturel, il revient au galop.* And again, on the other hand, they are subject to the environment, both physical and social.   By this latter I mean the complex of ideas, sentiments, and aspirations, of a more or less confused nature, which shape humanity.   Our evolution may thus undergo improvements, and may tend toward perfection. This is precisely where *education* comes in, a methodical education which adapts its effects to the age and the constitution of the individual ; which works without interruption, but without forcing the pace ; whose principles are those of a healthy culture, not those of *cramming* or over-loading. What could be more criminal than to make learned men or scholars of fifteen years !   Or to entrust difficult and protracted tasks to children who have not yet completed their eighteenth year !   Science denies the value of these intemperate methods, these abuses, which would pave the way, did not the legislator take serious precautions, for mis-shapen, sickly races, and a stunted humanity.

If, on the contrary, the normal development of the human personality is realised by effective means, all the aptitudes display themselves, and unfold completely and sanely.   Then each individual reveals his special capacities, whether for speculative science or for art.   Industry, which should assign the man to the task which suits him, in which he will turn all his talents to account, will quickly accomplish its work of *selection.*   And the same in all the trades or professions, which are nowadays so numerous ; a judicious examination, a fair and unerring investigation, will make it possible to apportion the work of society, the task of eternal progress, among those whose competence is recognised.   It is a matter of putting *the right*

man in the right place.   The classification of men is not the same thing as their subordination ; every man who knows a trade and follows it conscientiously ought to be proud of it ; the task of the labourer is one with the work of the engineer.   I will even go to the length of claiming, with Voltaire, that " the man who devised the shuttle had the best of it, with a vengeance, over the man who conceived the doctrine of innate ideas."

And lastly, it would be merely justice to take *moral worth* into account ; it is one of the levers of prosperity ; it is, in every way, the best safeguard against the temptations among which the mind may suffer shipwreck.   The idea of *duty* and *responsibility* is readily acquired when it is taught from early youth, and represented by the examples of home life.   It is thus above all an attribute of the family, and, in the long run, a hereditary virtue.

It appears to me that morality is more highly developed, at all events in France, in the lower strata of society ; it would attain an even higher development could poverty be diminished.   The man of the people possesses *frankness* and *sincerity* in a greater degree than the educated and refined member of society, for he has not learned the art of disguising his thought ; he speaks and acts naturally, and nature never deceives.

To the German physician Möbius, whose theory of the intellectual superiority of the male has already been mentioned (p. 42), the moral equality of the two sexes does not appear to admit of any doubt.   I think I have given the strongest reasons for disallowing the former claim ; but as for the latter, I will say, with the ancient philosopher : " Let us not venture to discuss this problem, for it would be an offence to the Divinity."

Let us only beware lest we stifle, by means of injustice and abuses, the flower of the morality of our race.   Let us do our utmost to encourage those who combine unfailing honesty with sound judgement, for they are the guardians of the treasure of civilisation.

CHAPTER IV

WORK AND FATIGUE

XXIX.—It has already been explained that the human machine is subject, as far as its motive force is concerned, to the same laws as inanimate motors. In its cells it possesses innumerable silent furnaces ; it feeds itself with fuel and oxygen ; it derives, from the chemical energy of the *nutriment* absorbed, both *heat* and *work* ; it charges the muscles and makes them ready to contract, thereby actuating the implements represented by the robust limbs of the working-man, the skilful members of the artist, or the agile digits of the typist, the author, the pianist, or the seamstress.

So much for the energy available. How does it act ? And how measure it, how discipline it, how use it with care and economy ? This is what we shall now briefly consider.

A. MUSCULAR ACTIVITY.—If we had not, in the magnitude of the respiratory exchanges, the true expression of *all muscular activity*, we could form only an approximate idea of it, for static efforts are not the same thing as work performed, and cannot be measured, yet they affect the resistance of the organism, and produce fatigue. It fatigues a man merely to remain *standing* all day, overseeing a workshop, even though he does not move a step.

This form of activity is the least useful. Usually activity involves *movement*, walking, running, or *work* [1] done upon various implements, and the expenditure of both physical and intellectual energy.

[1] Work done is of course expressed in terms of the effort or force exerted, multiplied by the distance over which it is exerted. Thus, when water is drawn from a well, the factors of the work done are the effort exerted on the rope and the depth of the well.

Our limbs or our bodies move, actuated by muscular contraction. When a limb moves away from the body its movement is a movement of *abduction*, and when it draws nearer to the body its movement is a movement of *adduction*. Its ventral position (the fore-arm outstretched, with the palm of the hand turned downward) represents the movement of *pronation ;* the contrary or dorsal position represents the movement of *supination*.

Not only does it assume a variety of positions, but the same limb will involve, according to circumstances, the contraction of different muscles, which combine and harmonise their effects. One supposes, for example, that the muscles of the upper arm actuate the fore-arm. But the muscles of the shoulder help to do so more effectually, the former acting upon the elbow when an effort of simple traction by the hands is intended. The highly flexible articulation of the wrist is hardly subjected to any effort ; it is very delicate, moreover, and better adapted to perform quick movements than forcible ones.

To the action of the muscles which produce the movement is added that of their *antagonists*, as in the case of the *flexor* and *extensor* muscles ; and it is thanks to a combination of muscular efforts that we are able to move a limb in the direction and with the degree of celerity desired. It would not, therefore, be sufficient, did we wish to estimate the muscular work performed in flexing the fore-arm, to know the force exerted by the biceps and the magnitude of the movement ; we should also require to know what force was exerted, what work done, by the triceps, its antagonist. The muscular system, as we know, acts under the control of co-ordinated nervous excitations, each group of muscles acting *synergetically*. For example, if we wish to raise our arms, the abductor, adductor, and levator muscles intervene, the first helping to carry the arm forward or backward. If we wish to *lower* the same limbs, the depressors will then come into play, not as antagonists of the levators, but as moderators of the falling movement. The *brachial biceps*, on the other hand, is not exclusively a flexor muscle ; it is also a supinator ; we feel its distension when we turn a stiff key.

F

The *rectus femoris* (see Fig. 11) is not merely an extensor of the lower leg ; it is also a flexor and levator of the thigh, and serves to maintain the equilibrium of the hips.

The modalities of muscular action are numerous, and are not without influence upon the *degree of fatigue ;* we ought to understand how to confine muscular action to the strictly useful effect, with the smallest expenditure of energy ; it is important to avoid superfluous contractions, and movements in which part of the effort is wasted or annulled. This economy is of the greatest value in *prothesis after amputation.*

Sports and games, notably boxing and fencing, are in certain senses comparable to industrial labour ; but in them the elimination of *useless movements* has been brought to a much higher pitch. Good athletes are careful to avoid such movements, for their reputations, and sometimes their lives, are involved. *Physical education* must employ the same economy, for the sake both of discipline and of health.

Use educates the activity of the muscles, and produces perfect regularity ; automatism, thanks to the bulbar reflexes, takes charge of our movements, and a kind of dynamic instinct eventually imposes its sovereign laws upon the human machine.

XXX. **The Measurement of Muscular Activity.**—The direct evaluation of all these forces is interesting work. To begin with, it gives us information concerning the difficulty of this or that handicraft, and enables us to determine if it can be practised by women, or children, or even by invalided soldiers, or the cripples of war and industry. It is equally necessary if we are to appreciate the progress of *physical education* and the restoration of muscular strength, and to compare the work accomplished with the energy expended upon it—a comparison which tells us if a good or a bad output, or ratio of efficiency, is being obtained.

We obtain these measurements of forces by means of graphic methods, by direct registration, according to the rules formulated fifty years ago by the famous French physiologist, Marey (1830–1904).

The muscles are made to act upon springs which, under the conditions of the experiment, undergo compression and a slight change of form. Each of these springs terminates in a disc. This compresses a small rubber ball. This ball, by means of a flexible tube, is connected with a small metallic cup, over which a rubber membrane is stretched. This is known as a *Marey tambour* (Fig. 19). Compression of the ball produces a pressure of air in the tambour, and raises the
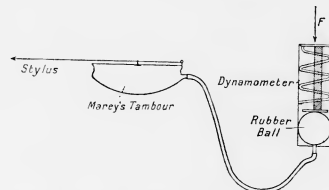
FIG. 19.—Diagram of Recording or Graphic Dynamometer.

recording lever or stylus which is actuated by the membrane. If we arrange the stylus in contact with a *recording cylinder*, such as is fitted to a recording aneroid barometer, we shall obtain a written record of the muscular efforts exerted, amplified to the desired extent (Fig. 20).

I have applied myself to devising dynamographic apparatus which can be adapted to all kinds of tools, and which give me, under any circumstances, clear and faithful graphic records.

If it is desired, for example, to analyse the efforts F and F^1, exerted by a man using a file in finishing steel or brass, the tool is fitted with suitable attachments precisely where it is gripped by the hands, and these attachments are connected with Marey tambours mounted on a *carriage*. In this way we may record all the forces in action, and all the components of these forces. It will readily be perceived that the vertical components, V and V^1, combine to press down upon the file and

to make it bite, while the horizontal efforts, H and H¹, cause the sliding motion, and therefore perform the *useful work* (Fig. 21).

Fig. 20.—Recording Cylinder with Marey Recording Drums, arranged to record the Efforts of a Man filing Metal.

Fig. 22 shows the file with its dynamographic attachments ; to these must be added a special support, which measures the pressure exerted upon the block of metal.

Fig. 21.—Analysis of the Efforts exerted in filing Metal.

The file is fitted at its free extremity, at D, with springs, each of which compresses a rubber ball, the attachments of

which record the pushing force and the pressure of the left hand ; while the handle encloses a spiral spring, S, and a rubber ball, B, which actuates the stylus recording the pushing effort of the right hand. For detailed calculations we must refer the reader to our volume on *Le moteur humain* (pp. 528–552), which shows how a number of tools and implements may be adapted for dynamographic purposes (spade, hammer, shears, wheelbarrow, etc.). However, we shall once more, in these pages, describe the *registering jointing-plane* and the *registering spade*. The thrust of the arm, acting upon the handle of the plane (Fig. 23), is decomposed into the horizontal effort which moves the tool, and the vertical effort, which presses the tool upon the plank to be planed. By means of rubber attachments suitably disposed this pressure is measured, as well as the total force exerted upon the handle ; from these data the horizontal

Fig. 22.—File with dynamographic Attachments.

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FIG. 22.—File with dynamographic Attachments.

component is deduced, which in this case represents the
resistance offered by the wood to the iron of the plane.
On the other hand, the plank is placed between two
parallel guides, which may at will be adjusted at varying
distances from each other. On each guide is fixed, along its
entire length, a very flexible rubber tube, which is pressed out
of normal shape by the lightest contact of the plane. If we
connect these tubes with Marey tambours, we obtain a written
record of the *jerks* resulting from unskilful movements on the
part of the worker.

Fig. 23.—Registering Jointing-Plane.

Lastly, the attachments which enable us to render a *spade*
dynamographic, whether it be employed in excavation,
embanking, etc., or in agricultural operations, are shown in
Fig. 24 ; they register the total thrust, or resistance of the soil,
and the efforts exerted in removing the spadeful of material
excavated.

XXXI. **The Measurement of Speed or Pace.**—As for the
rapidity of voluntary movements, it is possible to measure this
simultaneously with the measurements of the efforts put forth,
by the employment of a rapid *chronograph* measuring fractions
of a second. Even with the fingers, which are the most agile
members, it is unusual to accomplish more than seven move-
ments per second. Taking the case of the self-registering
plane, we can make sure of regularity of movement at any
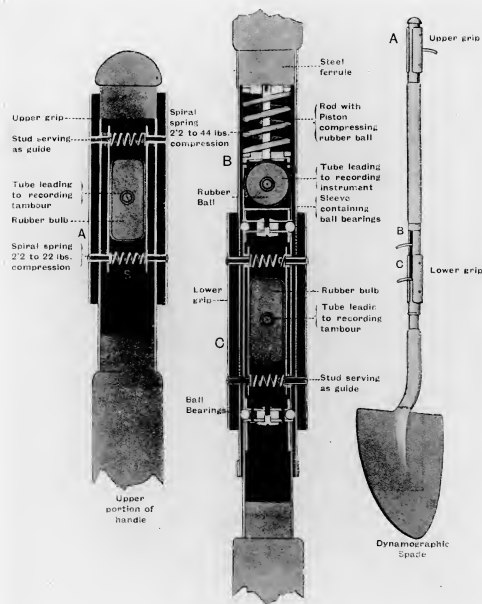
Fig. 24.—Dynamographic Spade (detailed Section.)

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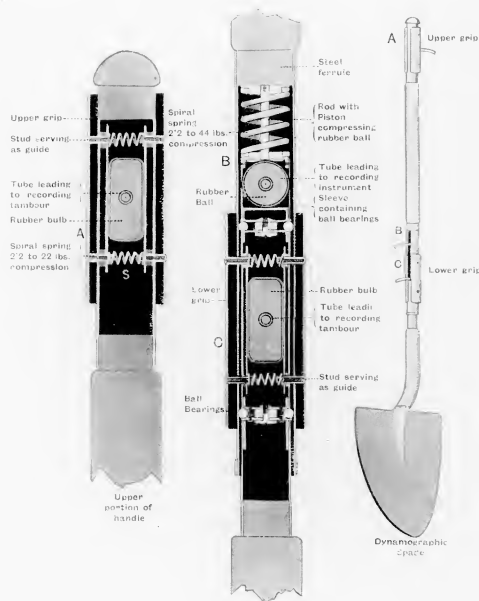
Fig. 24.—Dynamographic Spade (detailed Section.)

given speed ; while the number of jerks to right or left registered upon the recording cylinder will inform us of the faults to be corrected.

One might also make use of the cinematograph, recording
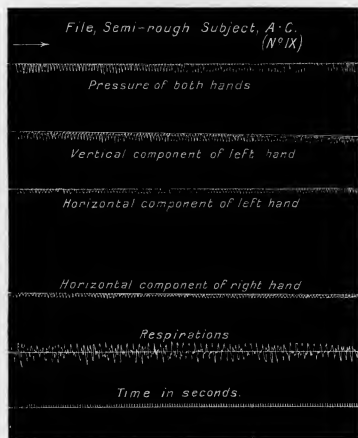
FIG. 25.—Graphic Record of the Work of a good Workman using the File.

on a film run at a known speed the various positions of the tool.

This method also enables us to note all the attitudes assumed by the body during work, and enables us to recognise any defects. Lastly, following the example of Dr. Gilbreth, we may attach a small incandescent light to the worker's hand, and obtain, by means of photography, the cycle of his move-

ments. *Cyclography*, if not an original method, has certain advantages which we cannot go into here.[1]

The combined graphic record will enable us to note the order and the intensity of the muscular efforts exerted, their rapidity, and their degree of regularity or uniformity, all these details being recorded with admirable fidelity and clearness. To these we may add the record of the respiratory efforts (Fig. 25). The active life of the worker has placed, so to speak, on the paper of the graph an indelible imprint, its personal signature.

XXXII.—B. THE EXPENDITURE OF ENERGY.—To the work thus performed by the man, and graphically measured, corresponds an expenditure of energy levied upon the reserves of the organism; not upon the nutriments which have just been absorbed, but upon those which the body-cells have had the time to elaborate, to fix, to bring to that particular state which enables them to become readily oxidised, and to produce energy.

The expenditure of energy is in proportion to the activity of the muscles, to the synergetic sum of their contractions; intensity, rapidity, and duration all being comprised in this activity, which extends to the nervous as well as to the muscular element. And all this produces *fatigue*, and regulates the consumption of oxygen respired, adding a further quantity to that which we already absorb during periods of repose. The total energy of the active man is thus a sum, in which one of the terms, that corresponding with periods of repose, undergoes hardly any variation, when the external temperature is constant, while the other term increases in proportion to the muscular activity.

Without entering into lengthy details concerning the measurement of the volume of oxygen consumed, we will explain, as an example, the principle of our method. The person experimented upon breathes through the mouth, which is convenient in the event of great fatigue—the nostrils being compressed by a little wooden clip, with padded jaws. A tube fitted with a *two-way valve* is held, by means of a rubber mouthpiece, between the lips and teeth ; the outer

[1] See the *Revue de Métallurgie*, p. 203, April, 1915;—*Revue générale des Sciences*, p. 173, 1916.

atmosphere is breathed in through one valve ; it is expired through the other valve into a rubber tube, passing through a bell-shaped container C and a gasmeter G (Fig. 26). The container is connected, by means of a fine rubber tube, with

FIG. 26.—Respiration Gauge.

a system of reservoirs containing mercury, R and R.[1] Accordingly as R empties itself into R[1] or the reverse, some of the air expired is shunted, or the sample contained in R is passed into a *eudiometer* for analysis.

We thus obtain the total volume of the air respired, or the

pulmonary ventilation effected during the experiment, and also the composition of the air expired.

Normally the atmosphere surrounding us contains 21 per cent. of oxygen, reckoning by volume. As there is less than this in the air expired, the difference represents the quantity consumed by the organism.[1]

Such, briefly described, is the respiration gauge, which enables us to estimate the expenditure of energy. It is mounted on a table running on rubber-tired wheels, which rolls to and fro without jarring the instrument, following the subject as he moves to and fro, enabling us to investigate normal or pathological locomotion, or physical exercises, or mechanical labour.

The mouthpiece is easily kept in the mouth, without any inconvenience to the subject, whatever the length of the experiment.

Knowing the total volume of oxygen utilised by the organism, we estimate it in terms of calories, as has already been explained, at the rate of 4·9 calories per litre. We thus obtain the expression of the energy developed by vital combustion.

The distribution of this energy is of a multiple character. It maintains the deep-seated physiological activities : the movements and the nutrition of the circulatory, respiratory, and digestive systems. It maintains the temperature of the body at a constant level, making up for the losses which it suffers by contact with the air and by radiation. Lastly, it provides for the intense activity of the muscles and the less onerous task of the nervous tissues. While in the case of an adult the expenditure of energy during repose amounts on an average to 2,100 calories during the twenty-four hours, cold increases it ; in the winter, with the thermometer only a few degrees above freezing-point, it amounts to 3,500 calories, while in summer, with a temperature of 77° to 86° Fahr., it falls to about 1,800 calories.

[1] Thus, we may find, in the eudiometer, 17 per cent. of oxygen instead of 21 per cent., or a difference of 4 per cent., when, if the total volume respired is 150 litres, the product $\frac{150 \times 4}{100}$ gives the total consumption of oxygen, or 6 litres.

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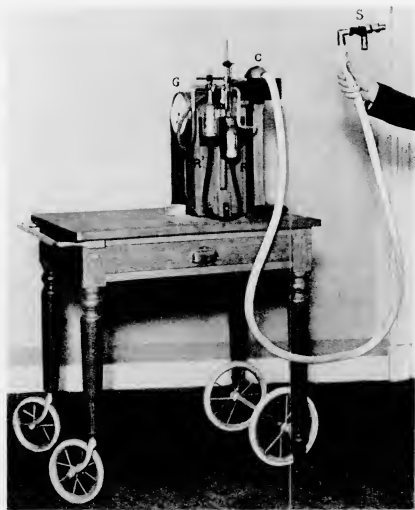
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If we reckon that the heaviest day's work consumes from 2,000 to 2,500 calories, and add this to the foregoing values, we reach a total of 4,000 calories in summer—but the heat, which diminishes the energy of the muscles, often makes it impossible to attain this—and 5,000 to 6,000 calories in winter, as the daily *ration of labour*.

This varying expenditure is maintained by means of alimentation ; but it is a notable fact that whereas any substance which can be burned can be employed in a heat motor, this is not the case with the living organism, for the latter is not indifferent to the quality of combustible supplied to it. *It can utilise as aliment any substance which it can elaborate in such a way that it may be stored in the body cells.* This is the only store which it can exploit immediately and without loss, and which is able to ensure its *uninterrupted* upkeep. *The expenditure of energy is continuous,* for any interruption would be a sign of death. *Life, therefore, is energy.*

XXXIII.—C. FATIGUE.—The physiological point of view offers this inestimable advantage over any other point of view, that it reveals the effects of excessive fatigue, and furnishes us with means of ensuring that it shall not exceed the limits of the normal. But for this physical training would be a fallacy ; it would lead to overwork ; it would not accomplish its aim. It must be added that organic disorders and affections of the nervous centres have become more frequent than humanity has ever known them as a result of this terrible war. Deficient cardiac activity is particularly to be looked for in discharged and wounded soldiers and war-cripples. It is therefore a most important matter to investigate the indications of fatigue.

Fatigue is the result of muscular and nervous phenomena which give rise to an increasing *malaise* or uneasiness, and above all a feeling of impotence. This feeling progresses through every stage, from a mere lassitude to the acutest suffering, and it persists for a varying space of time. It arises from various sources of excitation ; from the nervous fibres which terminate, as has already been explained, in the

muscles and tendons, and on the articular surfaces, and from the coverings of the viscera, in which Lennander has localised the origin of organic pain ; thence it assumes a general character, and eventually embraces the whole extent of the body. For fatigue is fundamentally an *intoxication* ; if the brain and the muscles function in a disorderly fashion, as a result of excessive efforts, or too great a rate of exertion, the blood is no longer able to cope with its task of purification. The waste products of this intense cellular activity accumulate ; the blood, loaded with toxic products, produces fatigue in any animal into whose veins it is injected. It acts to begin with upon the periphery, the seat of the sensitive fibres, so that even though the brain alone has been working, fatigue affects the muscular organs. It is a singular paradox to pretend, as certain pedagogues have done, that the mind may be refreshed by the fatigue of the body ! It is as good as a confession that they have never fatigued either.

On the other hand, it is essential to distinguish between *fatigue* and *pain*, for pain may often be wholly *accidental*, the result of an excessive or clumsy effort, or a faulty attitude, or a pathological condition ; in these various instances it is, moreover, confined to the limb or the organ affected, and does not invade the whole system. Neither in the organisation of physical education nor in that of mechanical labour should there be any room for this sensation ; for it signifies a vicious method.

A look-out for the *signs of fatigue* should be kept in respect of all the functions of life. To-day such investigations have hardly commenced.[1]   Let us consider the facts.

XXXIV.—(1.) *The Circulation of the Blood.*—We cannot in this place give a detailed account of the technical methods employed in such observations. We will only remark that

[1] A. Mosso, *La Fatigue* (French translation by Langlois), 1894 ;—Jules Amar, *Observations sur la fatigue professionelle* (*Journal de Physiologie*, pp. 178-202, 1914) ;—Stanley Kent, *Interim Report on an Investigation of Industrial Fatigue by physiological methods.* White Paper published by H.M. Stationery Office, 1915. *Second Interim Report on an Investigation of Industrial Fatigue by physiological methods.* Blue Book published by H.M. Stationery Office, 1916. Health of Munition Workers' Committee. *Interim Report.* Blue Book published by H.M. Stationery Office, 1917.

the person to be experimented on works an *ergometric cycle,* of which we shall have more to say presently. He actuates the pedals by the contractions of the leg muscles, or he works a crank by contracting the muscles of the arms (Fig. 27).

Records are taken of his *heart-beats* and of his *pulse,* and the *arterial pressure* is measured ; the first two operations are effected by means of the *cardiograph* and the *sphygmograph*

FIG. 27.—Taking a Graphic Record of the Pulse during an experimental Investigation of Fatigue.

(Marey), and the second by means of Pachon's *oscillometer,* which gives the *systolic* and *diastolic* pressures successively— that is, the highest and the lowest. However, I advise the experimenter to content himself with the record given by the cardiograph ; this instrument, applied as in Fig. 28, remains in place while the subject is exerting his strength, and its indications are sufficiently reliable.

The results of such experiments are interesting. Gradually, as the muscles continue to work in a normal and regular fashion,

the frequency of the pulse continues to increase : but provided that a maximum of *two hours of work* is followed by a *quarter of an hour of repose,* the average frequency does not exceed 120 *pulse beats per minute,* or about 50 beats per minute more than during repose ; and it tends to remain constant. On the other hand, if the pace of the work done exceeds the

FIG. 28.—Cardiograph and Pneumograph in Position.

usual limits, the pulsations become more rapid, quickly attaining a rate of 130, 140, and even 160 per minute. Such a rate as the last is most unpleasant and injurious ; fortunately it is fairly unusual, except in athletic sports (running, rowing).

But even when the number of pulsations, as a result of a moderate effort combined with a rapid pace, rises only to 120,

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Records are taken of his *heart-beats* and of his *pulse*, and the *arterial pressure* is measured ; the first two operations are effected by means of the *cardiograph* and the *sphygmograph*

Fig. 27.—Taking a Graphic Record of the Pulse during an experimental Investigation of Fatigue.

(Marey), and the second by means of Pachon's *oscillometer*, which gives the *systolic* and *diastolic* pressures successively—that is, the highest and the lowest. However, I advise the experimenter to content himself with the record given by the cardiograph ; this instrument, applied as in Fig. 28, remains in place while the subject is exerting his strength, and its indications are sufficiently reliable.

The results of such experiments are interesting. Gradually, as the muscles continue to work in a normal and regular fashion,

the frequency of the pulse continues to increase ; but provided that a maximum of *two hours of work* is followed by a *quarter of an hour of repose*, the average frequency does not exceed 120 *pulse beats per minute*, or about 50 beats per minute more than during repose ; and it tends to remain constant. On the other hand, if the pace of the work done exceeds the

Fig. 28.—Cardiograph and Pneumograph in Position.

usual limits, the pulsations become more rapid, quickly attaining a rate of 130, 140, and even 160 per minute. Such a rate as the last is most unpleasant and injurious : fortunately it is fairly unusual, except in athletic sports (running, rowing).

But even when the number of pulsations, as a result of a moderate effort combined with a rapid pace, rises only to 120,

to prolong the duration of the effort fatigues the circulatory system. This fatigue reveals itself by a *regular decrease* of frequency, the latter finally falling to 100, or sometimes to 96. The heart is no longer able to respond to the pace of the effort, and to satisfy the needs of the organism. The physiological synergy is deranged, if not destroyed (Fig. 29). Directly the observer notes this discordance between the muscular and cardiac functions he should bring the experiment to a close, or at all events greatly moderate its pace.
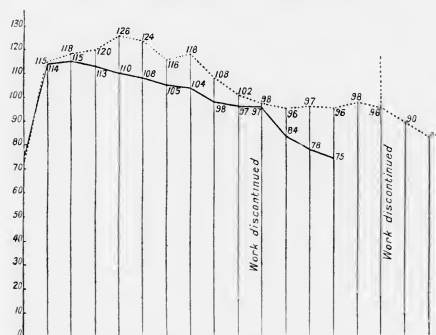
FIG. 29.—Rhythm of the Heart during Work (a Case of Fatigue).

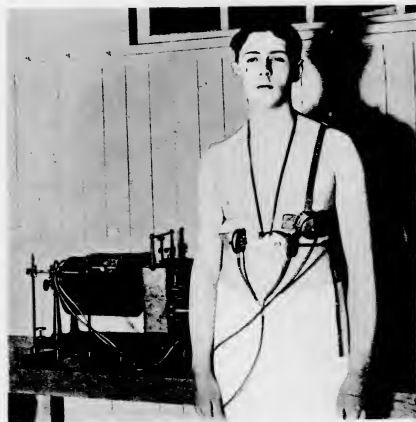The cardiac curves give us quite as much information concerning the cardiac rhythm as do the graphs of the pulse. We further learn from them that the amplitude, that is, the *force of the heart-beats*, increases, and that the heart undergoes a slight and temporary increase in volume. This latter fact has been observed by fatiguing the subject by causing him to walk upon a rolling track, and subjecting the thoracic cage to radioscopic examination.[1]

[1] Zuntz and Nicolai, *Berl. Klin. Wochensch.*, No. 18, 1914.

The ratio $\frac{\text{diastole}}{\text{systole}} =$ about 2, or even 1·50; the contraction of the auricles is accentuated, and the *right-hand undulation* of the systolic plateau descends toward the lower third of the curve, its normal position being in the upper portion. The aspect of the tracing taken during fatigue is characteristic (Fig. 30). It denotes a sudden expansion of the ventricles, and an absence of sustained cardiac effort. Careful scrutiny
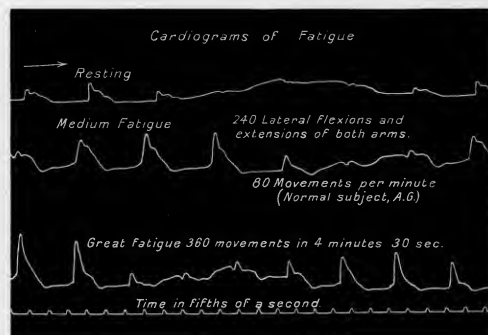
FIG. 30.—Graphic Record of the Heart of a young Gymnast (at Rest and during Fatigue).

of the curve enables us to detect a kind of *periodicity* in the systoles, producing a striking type of record (Fig. 31). We need not, therefore, linger over its description, still less over its interpretation.

As for *arterial pressure*, this amounts to 15 to 16 centimetres (about 6·0 to 6·5 inches) during repose, but often attains as much as 33 centimetres (about 12·5 inches) during exertion ; this too diminishes during extreme fatigue. Under conditions of medium activity, when the heart is still per-

forming its functions in a regular manner, the systolic pressure varies but slightly, oscillating about a value of 25 centimetres (10 inches).

We now perceive the nature of the indications of normal labour, which does not expose the subject to the danger of overexertion; the frequency of the heart-beats should be from 115 to 120, and the cardiograms should show signs of a systolic plateau, the undulation forming it being rather lower than during repose; the
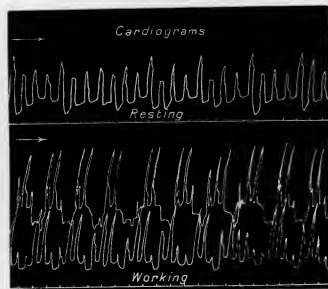
Fig. 31.—Cardiograms during Repose and extreme Fatigue (normal Subject).

maximum arterial pressure should be 25 centimetres (10 inches). Athletic exercises, which often overwork the cardiac muscle, render its previous examination absolutely necessary. The high pressure and abundant flow of the blood-stream, no less than its adequate renewal, are indispensable in the intense physical life of the athlete, as in all heavy mechanical labour.

XXXV.—(2.) *Respiration.*—Fatigue affects the respiratory function perhaps even more rapidly than the cardiac function. Not only does respiration become extremely frequent: it also ceases to be regular; it is dyspnœic, and of a jerky character.

The respirations may be registered by means of the *double pneumograph,* applied to the chest by means of a tape surrounding the thorax, or, better still, to the back, where it is less likely to inconvenience the worker (see Fig. 28).

The tracings of the pneumograph express the variations of amplitude and rhythm occurring in the thorax, as its muscles are more or less contracted (Fig. 32). But we may connect a special attachment with the mouthpiece of the respiration
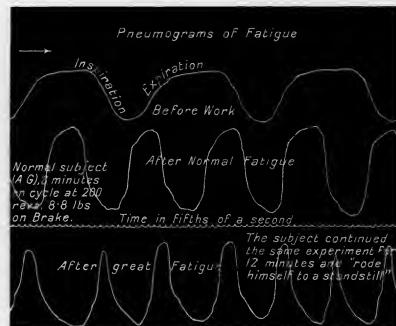
Fig. 32.—Respiratory Tracings taken by Means of the Pneumograph (normal Subject, working a Cycle).

gauge (as shown in Fig. 33), and record the movements of the breath in the lungs, thus obtaining what are known as *tonograms* (Fig. 34); records, that is, of the variations of pressure (from the Greek τόνος, pressure). For this purpose the valve is fitted with a stopper which is traversed by a small tube, which receives a rubber tube connected with a Marey tambour and recording cylinder. *Pneumograms* and *tonograms* combine to provide us with a complete analysis of the

respiratory function ; the tonograms being more accurate and more significant of the actual condition of the pulmonary cavities. Both forms of tracing reveal the derangements which may occur in the lungs themselves. or in the muscular

Fig. 33.—Showing the Valve of the respiration gauge fitted with a " Shunt " for making tonographic tracings, also the employment of the pneumograph (young Athlete, 18 years of age, A.G.).

system which causes the lungs to perform their function (Figs. 35 and 36).

We know that during repose the duration of the expiration, e, is at least double that of the inspiration,[1] i. The ratio $\frac{e}{i}$ is

[1] The difference is generally taken to be less than this.—(*Ed.*)

progressively diminished during fatigue, while the respirations become deeper and deeper. At a certain point this ratio $\frac{e}{i}$

Fig. 34.—Tonograms.

becomes greatly diminished, the ventilation of the lungs is no longer ample, and the flow or delivery of air is less considerable. The volume of air expired per minute, which previously underwent a progressive increase—it usually attains

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Fig. 34.—Tonograms.

becomes greatly diminished, the ventilation of the lungs is no longer ample, and the flow or delivery of air is less considerable. The volume of air expired per minute, which previously underwent a progressive increase—it usually attains

a figure of 20 litres during labour—tends to diminish.   Thus, during a case of normal fatigue the following readings were obtained on the respiration gauge :

During repose, average delivery per minute, 7 litres.
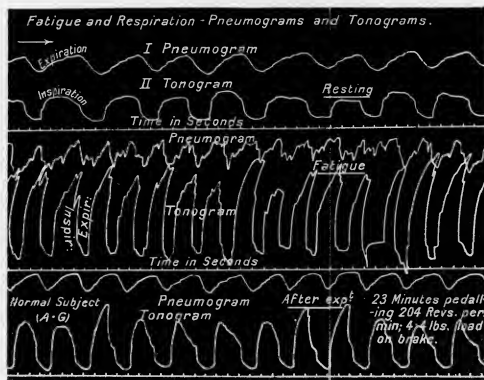
FIG. 35.—Tracings of deep Respiration during rapid Work (Pneumograms and Tonograms).

Working the cycle, 192 revolutions per minute, load on brake 2 kilogrammes : 13·20, 19·80, 20·75, 21·35, 20·70, 19·70, 22·50, 20·85, 22· 5, 20·0, 22·0, 20·40, 20·60, 19·50, 20·90 litres.   Or an average of 20·25 litres.

The curve shown in Fig. 37 shows a plateau signifying a phase of constant ventilation, which disappears only on the threshold of the dangerous phase, that is, the phase of over-exertion.

We may therefore assert that while normal exertion increases the ventilation of the lungs, and even slightly increases the

diameter of the bronchial tubes,[1] great fatigue diminishes the regularity of the gaseous exchanges ; it is then that *carbonic acid gas*, a toxic product of the vital combustion, accumulates
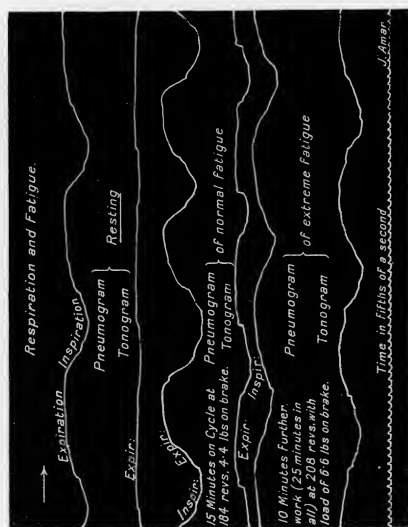
FIG. 36.—Tracing taken during quick and heavy Labour; the Worker is threatened with "Loss of wind."

in the blood and causes *breathlessness*, while the resistance of the nervous centres, and consequently the muscular energy, rapidly diminishes.

[1] Haldane and Douglas, *Journal of Physiology*, Vol. XLV., p. 235, 1912-1913 ; —Krogh and Lindhard, *ibid.*, Vol. XLVII., p. 30, 1914 ;—Krogh, *The Respiratory Exchanges of Animals and Man*, London, 1916.

The most elementary observation shows also that the respiratory troubles of fatigue are due far less to exaggerated muscular effort than to the *excessive rapidity* of the muscular contractions, which produces a lack of harmony between the synergetic rhythms of the vital functions.

It is to be noted, on the other hand, that the respiration becomes prolonged whenever a great effort of some duration is exerted (Fig. 37) ; a nervous ramus, emanating from the bulb, gives rise, in particular, to a prolonged expiration. But a sustained effort tends to become impossible in the fatigued state of the organism, because the bulbar intoxication precipitates the activity of the nerves and throws it out
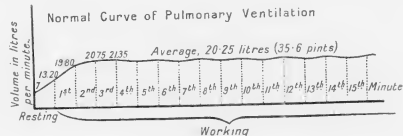
FIG. 37.—Curve of Pulmonary Ventilation.

of gear ; the expirations become short and jerky, a sign of breathlessness. It is possible, however, to store up oxygen by means of a very deep inspiration, and to prolong the duration of the expiration ; but this cannot be done often, nor for longer than two minutes. The Arab divers of Ceylon, whose trade is sponge-fishing, remain under water for 90 seconds.[1] Despite this effort, which appears to immobilise the thoracic cage, the breath oscillates in the lungs, as is shown by a tonogram. The lungs retain their rhythm and their amplitude (Fig. 39).

Let us now measure the consumption of oxygen : we shall find that it increases, under the same conditions of labour, with the advance of fatigue. The muscular engine yields a poorer and poorer output ; it becomes less efficient ; it begins

[1] Vernon, *Amer. Journ. of Physiol.*, Vol. XXI., p. 126.

to waste energy. On the other hand, I have observed a greater efficiency, an economy, when the effort and the pace were moderated so that the work was accomplished without great fatigue.[1]

At what inferior ratio of efficiency are we to regard the continuation of work as dangerous ? This is a very complex problem, for the yield depends upon the worker himself ; it is a personal coefficient ; it has reference to a plainly specified sphere of activity, and cannot be applied generally to all. We
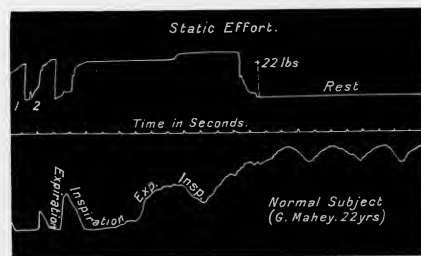
FIG. 38.—Pneumograms showing the expiratory Arrest of the thoracic Rhythm during a Static Effort.

should have to make some sort of experiments in order to estimate the depreciation suffered by fatigued muscles. Moreover, such a thing may occur as *static fatigue,* produced not by movements, whether useful or useless, but by the mere fact of exerting force ; this exhausts the peripheral nerve-terminals[2], and complicates the interpretation of the respiratory phenomena, which are consequently no longer exclusive of all other physiological data.

[1] *Le Moteur Humain*, p. 255-256.

[2] K. Frumerie, *Skand. Arch. f. Physiol.*, Vol. XXX., p. 409, 1913.

XXXVI.—(3.) *Neuro-muscular Energy.*—It will be understood that the *feeling of impotence* which is the sign of fatigue is localised in the neuro-muscular system. A man who sets off running at a rapid pace is inevitably, sooner or later, forced by this sensation to relax his effort and to slacken speed.

FIG. 39.—Tonograms taken during Static Effort.

There are various means of verifying this fact. To begin with, we may employ the ergometric cycle, actuated by the pedals or by a crank. We may employ a braked wheel, the brake being loaded with a weight of 6 kilogrammes, turned at a rate of 200 revolutions per minute. The wheel inscribes a record of its own revolutions, by means of an electric contact, and we presently note that the tracing exhibits longer and

FIG. 40.—Cheirograph registering the muscular contractions of the Fingers.

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FIG. 40.—Choirograph registering the muscular contractions of the Fingers.

less regular intervals. With the *cheirograph*,[1] which we shall describe later, the decrease of muscular activity may be followed, either in the fingers separately, or in the whole hand, or in the wrist (Fig. 40). The rhythm is measured by a *metronome*, and the weight to be moved by the muscular contractions does not vary (Fig. 41).

The data relating to the form and frequency of the muscular contractions being thus determined, it is obviously only the amplitude of the contractions, the height through
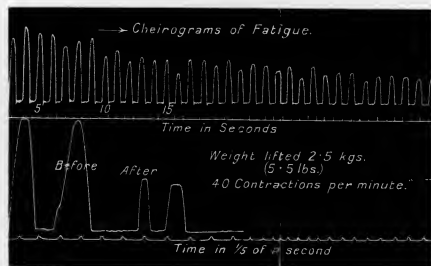
FIG. 41.

which the weight is lifted, which is diminished by fatigue. The work performed, then, is less and less. The *appearance* of a cheirogram is characteristic ; the crests of the tracing are lower and lower as fatigue advances, or as it is increasingly affected by circumstances : by bad food, lack of sleep, moral depression, high temperature, alcoholism, or some unapparent condition of impotence.

To a practised eye, I might remark, the comparison of the cheirograms taken before and after an experiment should

[1] J. Amar, *Le Moteur Humain*, p. 391 ; *Journ. de Physiol.*, p. 849, 1915.

permit of an estimation of the degree of fatigue. If we display such a tracing by rapidly rotating the recording cylinder, we shall note the flagging of the muscular effort in all the phases of the curve. The will does not act upon the muscles by a single impulse ; the nervous centres have to multiply their impulses, and then the weakness of the contraction betrays the *simultaneous* fatigue of the nervous system ; simultaneous because the muscular fibre itself, above all, becomes fatigued, becomes less irritable and less elastic ; its very elementary structure becomes impaired. After very violent movements, after very great efforts, the muscles suffer from *contracture ;* they become rigid, only slowly and with difficulty recovering all their original flexibility. We have instances of such contracture in the *rheumatic stiff neck,* which affects the sternocleidomastoideus ; or in the spasm known as *writer's cramp,* to which typists and seamstresses are subject as well as authors.

The fatigue of the nervous system is in proportion to the number of motor impulses which it is obliged to furnish to the muscular system in order to cause the latter to function ; this expenditure is heavy in work which demands movements repeated with great frequency. Short steps, very often repeated, are more tiring than good long strides ; and here we see why in certain kinds of work which do not require strength there is considerable nervous exhaustion, while fatigue soon makes its appearance.

A further consequence of this phenomenon is that disorders of the *general sensibility* are produced ; the nerves react less swiftly ; the personal equation increases ; the sight becomes less acute ; this is the *ocular asthenopia* of compositors, shoemakers, etc., in which one can no longer distinguish colours without increasing the intensity of the light ; at the same time the cerebral activity is diminished, ideas or images being less quickly distinguished by the mind.

The *tactile sensibility,* the source of our most frequent sensations, and our principal means of education, is also in turn diminished. It may be measured by touching the surface of the skin with two ivory points ; the normal separation of the

points of this special compasses or *aesthesiometer* has to be increased, so as to include a larger sensitive area. These various manifestations of nervous fatigue often result from a deficit of oxygen in the blood, or an excess of carbonic acid gas due to working too rapidly. Under these circumstances the *excitability of the nervous centres* diminishes, at all events for a certain time,[1] involving a diminution of the peripheral sensibility. Voluntary actions and reflex actions also are performed in a hesitating manner; sometimes they become disordered. For example, a young girl who uses a skipping-rope too long at a stretch eventually makes mistakes, and her movements become confused.

All these factors, at which I can give only a rapid glance, are measurable values; and we may draw up tables of figures representing the extent of these reactions before and after fatigue, which will furnish us with useful information.

In many cases I have been able to replace the tracings of the cheirograph by a more expeditious method of determining the greater or less *resistance of the nervous centres ;* the subject at a given moment seizes two weights of 5 kilogrammes (about 11 lbs.) which are placed within his reach, one on either hand, his arms being outstretched laterally and in a horizontal line. He must not allow his arms to fall, save as a result of fatigue; when this occurs the arms begin to droop and to tremble. We note the duration of this static effort, and it is repeated at intervals of a minute, as long as it is judged necessary to continue the experiment.

The product of the weight and the time, $p \times t$, in kilogramme-seconds or pound-seconds, varies in different individuals; at the beginning of the experiment the time value may vary from 18 to 20 seconds. But it is to be noted that in an hour's tests the *endurance*, expressed by the total of the products $p \times t$, is found to be characteristic of a man, and often of a group of men addicted to the same form of muscular exertion. In twenty instances, for example, it had an almost *constant*

[1] Altobelli, *Arch. ital. Biol.,* Vol. XL., p. 99, 1903; Piotrovsky, *Du Bois-Reym. Arch. f. Phys.,* p. 205, 1893;—Baglioni, *Arch. ital. Biol.,* Vol. XLII., p. 83, 1904.

value. The endurance limit reveals itself thus : to begin with there is a determined effort, then a sudden fall, and an absolute refusal of the muscles to bear the weight any longer. After an hour's rest, the curve again declines very rapidly, and one is justified in saying that nervous motor excitation tends to become exhausted, just as does the muscular energy. The shape of the *curves of endurance* is that of a *hyperbola* (Fig. 42). For example, we may obtain such results as these : 44″, 30″, 29″, 19″, 16″, 15″, 14″, 13″, 13″, 11″, 10″, 11″, 10″, 11″, 11″, 8″, 10″, 11″, 11″, = 308″, or a total of 308 × 10kg., or, 3,080 kilo-

General form of Curves of Endurance.
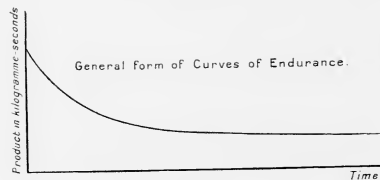
Fig. 42.

gramme-seconds. On an average a healthy adult, not suffering from fatigue, attains a total of 3,000 kilogramme-seconds. All striking irregularities, and all values lower than 2,000 kilogramme-seconds, betray great fatigue of the nerve-centres.

XXXVII.—(4.) *Biochemical Indications of Fatigue.*—The nature of fatigue, as we have already seen, is an intoxication, which, occurring at the points where activity is at its maximum intensity, gradually extends to the entire organism.

The poisons of fatigue result from the transformation of the *cellular albuminoids*, which is always extremely bad for the health, for not only is it extravagant, necessitating far more oxygen than if fats or sugars were concerned, but it liberates toxic bodies or *ponogenes*. These are formed more particularly when the muscles are putting forth excessive efforts. These

products are based upon *nuclein*, whose origin is the *nucleus* of the cell ; they are acid, and *phosphorised* or *nitrogenous*. These nuclein bases are also found in the urine, together with phosphates and uric acid. This last, eliminated by the organism at the rate of 8 milligrammes per kilogramme during the 24 hours, this rate being constant,[1] is more abundant after fatigue.[2] And all these products, conveyed by the blood, poison the organism. We have seen that their injection into the veins of an animal causes a depression of the vital forces, and the disorders peculiar to fatigue ; they diminish the muscular excitability, involving an increasing expenditure of nervous energy, and an actual wasting of the vital resources ; they impair even the living tissues, those of the muscles and the nerves ; they impede the regularity of the phenomena of respiration and circulation.

While normal activity reduces the proportion of the urinary toxins,[3] intense labour and extreme fatigue visibly increase it ; and Bouchard has noted that they produce a certain *narcotic* effect, which may vary from mere somnolence to death.

Unfortunately the measures taken, when examining urine, to detect the extreme limit of *physiological fatigue*, are still deficient. Neither from the *analysis of the blood* nor from the toxicity of the perspiration can we obtain more reliable information. We must combine a large number of data—briefly indicated here—in order to appreciate the intensity of fatigue.

The truly physiological characteristic of the latter is proved by the disappearance of all its effects after *rest* and *sleep*, both necessary things, and both demanded by the auto-intoxication itself. The toxin which causes sleep, the *hypnotoxin*, is formed during the waking state ; it is found in the blood, and more particularly in the cerebro-spinal fluid ; it is said to produce temporary degenerative changes in the frontal lobe of the brain.[4] Fatigue and lack of sleep give rise to a torpid con-

[1] Faustka, *Pfl. Arch.*, Vol. CLV., p. 523, 1914.
[2] Herther and Smith, *Maly's Jahrb.*, Vol. XXII., p. 200, 1892 ;—Dunlop, etc., *Journ. of Physiol.*, Vol. XXII., p. 68, 1898.
[3] Ch. Bouchard, *Leçons sur les auto-intox. dans les maladies*, Paris, 1887 ;—Colasanti, *Ricerche Istit. Farmacol. Sper.*, Vol. II.-IV., 1895-1899.
[4] H. Piéron, *Le Problème physiologique du sommeil*, Masson, 1913.

dition of the organs of movement, and relax the tonicity of the muscular system, exerting a depressing effect on the innervation ; they render rest and sleep inevitable, for at a certain moment they become *inhibitory*, constituting a mechanism of defence against exaggerated activity. *The oxygen of the blood will restore the vitality of the organism.*

If, through a false conception of the laws of work, one disregards these warnings of fatigue, the normal limits are quickly passed ; the intoxication becomes aggravated, giving rise to a *febrile stiffness*, headache, and other painful symptoms. The resistance of the nerve-centres becomes greatly diminished, and, in short, the resistance of the organism collapses ; and it is this lessening of resistance which awakens latent imperfections and maladies, which have very often been unsuspected ; it is this which breaks down the reaction that infectious germs find it so difficult to contend against. Typhoid fever or tuberculosis declares itself. We know what is the dismal fate of armies exhausted by warfare.

The object of the physiological organisation of human activity is to render impossible the circumstances which give rise to overwork, and end by ruining the health. Its aim is the conservation of the human race by means of social hygiene.

CHAPTER V

THE FACTORS OF LABOUR

XXXVIII.—In order to organise human labour, we must understand the laws of muscular and nervous activity, and the numerous factors on which they are dependent.

Even among the ancients precepts were current to the effect that one should exercise the body before and not after meals, and that such exercise should be continued " until a slight lassitude is felt, until a little perspiration appears, or at least until a warm vapour is exhaled by the exertions of the body." [1] These rudimentary ideas of physiology and hygiene were, however, entirely disregarded when the army was in question. The military ideal, especially among the Romans, was one of the most rigorous training, until the soldier was able to cover distances of twenty-five miles a day with a load averaging about 77 lbs. It must be admitted that such a life as this gave the soldier a tough constitution, and that the organism became accustomed to extreme fatigue.

The principles of physical training were in the course of time forgotten, and under Louis XIV. victories were dearly bought. In 1734 Montesquieu remarked with justice : " We note to-day that our armies are largely perishing owing to the immoderate exertions of the soldiers ; yet it was by means of immense exertions that the Romans saved themselves. The reason of this is, I believe, that their hardships were continuous, whereas our soldiers, on the other hand, pass incessantly from extreme exertion to extreme idleness, which

[1] Galen, *De Sanitate tuenda*, Vol. II.

98

of all things in the world is most likely to kill them. *We no longer have a just idea of bodily exercises.*" [1]

This just idea could have been obtained only by consulting Nature, and Nature, according to Newton, creates nothing but geometry, and derives her inspiration from the principles of this geometry.

Galileo [2] demonstrated the fact that of all our muscles that which works without resting, without irregularity, and which reveals itself as truly *indefatigable*, is assuredly the *heart*. It possesses a great mass, and it contracts at the rate of about seventy-two times per minute ; and as " it moves only its own mass," this may be the explanation of its indefatigability. [3] The other muscles, on the other hand, have to move the skeleton, and sometimes the entire weight of the body, as in the case of the leg muscles.

These speculative views of the great Italian scientist are in agreement with our modern ideas as to muscular effort. There is, in truth, for every locomotive apparatus, a *rhythm of contraction* and a *resistance to be overcome* which is perfectly adapted to its normal action, although this has the appearance of being undefined. Further, there are certain values which correspond to *the most economical rhythm and effort,*[4] those which entail the least expenditure of energy.

In this connection we can do no more than briefly formulate the laws determined by the physiologists, and in particular by Chaveau.

XXXIX. The Laws of Chaveau.—1. *The expenditure of energy is in proportion to the muscular effort of contraction, to its duration, and to the degree of contraction.*—The meaning of this first law is obvious : the energy expended, or the

[1] Montesquieu, *Considérations sur les causes de la grandeur des Romains et de leur décadence*, p. 10 (ed. Barckhausen, Paris, 1900).

[2] Galileo (1564-1642), *Opere*, Vol. XI., p. 558 (Milan ed., 1811).

[3] But see note on p. 28. The absence of rest in the case of the heart is apparent only, since a part of every second is devoted to repose. Moreover, besides " its own mass " the heart moves the mass of the blood.—ED.

[4] If all our muscles could operate under the same conditions as the heart they would produce in 24 hours nearly 3 million kilogram-metres of work, or enough to enable one to make the ascent of Mont Blanc four times over.

fatigue produced, increases if the efforts are more intense and more protracted ; but it must be added that this fatigue, all other conditions being equal, is doubled if the shortening of the muscles is twice as great. The observation of a good workman will confirm this portion of the law : in pushing a wheelbarrow he will allow his arms to hang straight in place of

FIG. 43.—Position of Arms on lifting Wheelbarrow.

flexing them, thereby exerting the same sustaining effort with the minimum of fatigue (Fig. 43).

If it is on occasion necessary to exert great muscular force, it must be remembered that *the latter increases less and less rapidly as the muscle approaches the limits of its contraction.* The effort of contraction should not be carried to its limit,

or there will be waste of energy. Violent exertions constitute abnormal conditions of muscular activity, whose consequences are irreparable.

2. *The expenditure of energy required to perform a given amount of work diminishes in proportion as the rapidity of the muscular contractions increases.*—But this is true only within certain limits of speed, beyond which *nervous exhaustion* will ensue, together with profound physiological disturbances. As I have already remarked, a rapid gait, or a rapid rate of work, is permissible only when it does not overload the organs of circulation and respiration. Under such conditions speed is really economical. Modern industry, which demands the qualities of skill and speed far more than strength, should confine itself to these *economical speeds*, of which the Taylor system suspected the existence, although it could not state what they were.

3. *There is a most favourable effort and a most favourable speed for the performance of the maximum of work with the minimum of fatigue.* This is a consequence of the preceding law, and the determination of this effort and this speed constitutes the real object of the scientific organisation of human energy. Whether the most delicate kind of work or the heaviest labour is in question, the force exerted, and the pace of the work, should always be duly proportioned, the *sole* guide being the data obtained by experiment.

4. *Law of Rest* (Jules Amar).—*A muscle returns more speedily to its condition of repose in proportion as its work has been more rapidly performed.*—This law, formulated in 1910, is entirely comparable to the law of the cooling of heated bodies. The temperature of a body which has been heated falls at a rate proportional to the temperature to which it has been raised (Newton). Similarly, the consumption of oxygen, which expresses the expenditure of energy, decreases progressively from the termination of work until the condition of repose is regained, and this decrease proceeds rapidly, the return to the initial condition occurring quickly when the work has been strenuous—of course within certain limits. The law of this decrease enables us to determine the *interval of rest* which

fatigue produced, increases if the efforts are more intense and more protracted ; but it must be added that this fatigue, all other conditions being equal, is doubled if the shortening of the muscles is twice as great. The observation of a good workman will confirm this portion of the law : in pushing a wheelbarrow he will allow his arms to hang straight in place of

Fig. 43.—Position of Arms on lifting Wheelbarrow.

flexing them, thereby exerting the same sustaining effort with the minimum of fatigue (Fig. 43).

If it is on occasion necessary to exert great muscular force, it must be remembered that *the latter increases less and less rapidly as the muscle approaches the limits of its contraction.* The effort of contraction should not be carried to its limit,

or there will be waste of energy. Violent exertions constitute abnormal conditions of muscular activity, whose consequences are irreparable.

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is necessary on each occasion to restore the physiological conditions which obtained at the outset, and to divide the work into reasonable shifts. In this way a large daily output will be obtained without impairing the resistance of the organism. In the same way the degree of ventilation progressively decreases; it should resume the value normal to periods of repose *four minutes* after the work, whatever it may be, is ended. The tonographic curves also return to their initial amplitude (Fig. 44).
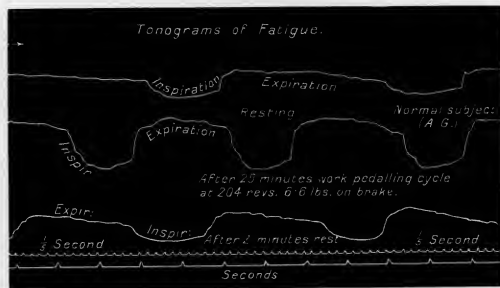
FIG. 44.

The whole science of human labour is condensed in these four laws, and the whole *art of working*, together with the whole of physical education, resides in their application. Duly to proportion effort and pace, to enforce intervals of repose—this is the secret of a normal activity, exempt from overwork, and, what is even better, favourable to the complete development of the functions of life. Whether in physical or intellectual exertion, everything is a question of measure, of discipline; that is to say, of *order* and *harmony*.

But this order and this harmony must yield both an outward and an inward irradiation, must control the living machine internally as well as in its relations with the outer world, for life is subject to the incessant influence of numerous *physiological* and *cosmical* agencies. Human activity is therefore dependent upon these, and we shall see by what powerful bonds they hold it and control it.

XL.—A. INTERNAL FACTORS OF WORK: OUR FOOD.—No motor can fulfil its function and perform work unless it is suitably *fed.* In the living motor the fuel is known as food or *aliment*, and the phenomenon of combustion bears the name of *nutrition*; it is, as we have seen, an oxidation affecting the *reserves of the body-cells.* " It is not the food eaten at the time that furnishes the energy employed in the physiological tasks of the organism," says Chaveau, " but the potential created with the food which one has eaten *previously.*" [1]

These physiological processes require the presence of *oxygen* and *water* and certain *saline substances*—salts of lime (carbonates and phosphates) and of soda (chloride of sodium), which consolidate the bones and participate in the processes of digestion or humoral equilibrium. Our alimentary rations almost always contain the necessary salts, and the 2 to 3 litres of water which an adult requires. And all our foodstuffs contain, in varying proportions, three kinds of *alimentary material*: *fats* (bacon, butter, etc.), *albuminoids* (white of egg, lean meat), and *carbohydrates* (sugars and starches). Experience has shown that alimentation should furnish our bodies with *one gramme of albuminoids* per *kilogramme of body weight* in order to make up for organic wear and tear. Above all, it has taught us—and the theory of energetics confirms this—that the work of the muscles, and probably that of the nervous system, *consumes carbohydrates almost exclusively.* The true source of available energy resides in these saccharine aliments, which are derived from the *glycogen* accumulated in the liver. Proceeding from the liver to the muscles, they

[1] It is impossible to enter into the problem of alimentation here. I must refer the reader to *Le Moteur Humain*, pp. 176-217.

are there transformed into *useful* or *mechanical energy*, almost without waste ; 100 calories of the said aliments really yielding 100 calories of available work, either in the muscle-cells or the nerve-cells. The fats and albuminoids, on the other hand, are a wasteful fuel, *less digestible* than the carbohydrates and not so pure ; this is especially true of the albuminoids, for they give rise to the toxic products which hasten the advent of fatigue. In the process of transformation they lose, respectively, 15 per cent. and 45 per cent. of their available energy, a loss which takes the form of a mere production of *heat*, which is a *degraded form of energy.*

Thus, the more active the life we lead, the greater use we shall make of the foods which contain carbohydrates ; and there is, in principle, a *minimum of albuminoids*—a comparatively small minimum—which should be absorbed by the body, and a *larger minimum of carbohydrates*. With the latter excess is an advantage ; with the former, an inconvenience, and often a danger.

Let us add that food best stimulates the digestive secretions when it is *slightly seasoned ;* that it is more digestible in some states than in others ; concerning which we shall give a few hints later on. The manner in which a dish is prepared, according to Pavloff, acts in a *psychical* or mental fashion on the powers of digestion (see § 10) ; so that the traditions of the culinary art are deserving of respect. It is enough to improve the quality of the food provided and to provide it in sufficient quantities.

XLI. Hunger, Inanition.—Bad or insufficient alimentation depresses the vital forces and gives rise to anaemia. In *inanition* nervous disorders may make their appearance, although the brain is of all the organs that which offers the greatest resistance to material exhaustion. But the muscles suffer great losses ; hence it is the labourer who suffers most from *hunger.* It is the same with the *child,* by reason of the necessities of *growth ;* the child who has been ill-nourished suffers damage which the best of diets will never make up for. I have found that it is of advantage, when endeavouring to

repair such damage, not to exceed a proportion of 2 grammes of albuminoids to the kilogramme, and to depend upon carbohydrates ; in other words, the process of repair must be progressive and gradual. I would say as much to those young men who are ardently devoted to athletic sports, and who undergo exertions whose effects can be repaired, and which can be rendered useful, only by a correct alimentation.

Hunger is a defensive sensation, which begins by a dragging pain in the stomach, accompanied by powerful contractions. By means of thin bladders of rubber introduced into this organ it is possible to register these contractions, and to measure their intensity, their rhythm, and their synchronism with those of the lower oesophagus.[1] The pangs of hunger are next reflected by the pharynx and the temples, producing *headaches.* They are keener during fatiguing exertion, especially in winter.

Lastly, we know that some persons suffer from *bulimia,* or a morbidly large appetite, and are obliged to eat incessantly in order to satisfy their devouring hunger. But, apart from this abnormal condition, *one should avoid excessive eating, and beware of the refinements of cookery.* Unfortunately we eat too much, and we vary our food too greatly. The result is an excess of digestive labour, which involves a supplementary expenditure of energy ;[2] the stomach becomes dilated, the respiration is embarrassed, while vertigo, insomnia, and cardiac acceleration often make their appearance ; one becomes unfit for hard physical work, and even the mind is obscured. The toxic effect of these copious repasts is absolutely incontestable.

And, on the other hand, an excess of alimentary excitation fatigues the nerves of the digestive system. "The majority of choice dishes . . . irritate the organs of digestion and secretion in an injurious manner."[3] The case is complicated by the appearance of more serious disorders, such as rheumatism, gout, albuminuria, or obesity, according as the diet

[1] Carlson and Lukhardt, *Amer. Journ. of Physiol.,* Vol. XXXIII., p. 126, 1914.
[2] Laulanié, *Comptes Rendus Biologie,* p. 548, 1904.
[3] E. Metschnikoff, *Etudes sur la nature humaine,* p. 379, Paris, 1908.

is chiefly fatty or albuminous. An abundant diet is the glaring defect of middle-class society.

XLII. Alimentary Rations.

—It must always be remembered that the *alimentary ration* which will suffice to make up for our material expenditure, whether resting or working, and to cover the *expenses of bodily maintenance*, must be regulated by the mass of the body and the amount of muscular work performed. In order that it may be a true *ration of maintenance* it must suffice to make up for the wear and tear of the organism, and to *maintain the weight of the subject*. A constant weight is, in the adult, evidence of the integrity of the functions and the suitable nature of the ration. Abstinence from albuminoid foodstuffs results in organic wasting ; the weight decreases by about 1 per cent. daily.[1] The diet, therefore, must supply, in addition to the necessary calories of heat, an alimentation perfectly adapted to the most definite physiological needs. It should contain the *minimum of albuminoids* or *proteids*, which, as we have already seen, is 1 gramme per kilogramme of body-weight, and a *minimum of carbohydrates*, the proportion of which will increase with the severity of the work performed. Fats, which will not be largely represented in these rations, will, however, be present in larger proportions when the weather is cold.

And these foodstuffs should always be prepared in such a way as to stimulate the *appetite*, that complicated reflex by which the body and the mind interpret their inner life, a reflex which it is profitable to consult. Food should always be well masticated and slowly ingested into the alimentary canal. It would seem that there were formerly, in Rome, persons whose duty it was to teach the art of mastication. And more recently the *Fletcherites* have made an important hygienic duty of the act of mastication. Fletcherism deserves more than a mere mention. In 1890 a wealthy American, *Horace Fletcher*, hardly forty years of age, resolved to cure himself of an evil from which he suffered greatly : *obesity*.

[1] S. Hataï, *Amer. Journ. of Physiol.*, Vol. XII., p 116, 1904

" He had become incapable of conducting his business, of frequenting the clubs, of fighting the battle of social life . . . he found himself so physically disordered that the insurance companies refused to accept him. . . . Then he bethought himself that the derangement of his mechanism was due especially to *over-eating*, and he himself sought the method of treatment : this was an *economical alimentation*." He decided upon a diet containing a large proportion of carbohydrates and a quantity of proteids corresponding to 0·60 grammes per kilogramme of body-weight. This diet consisted only of vegetables, cereals, sugar, and milk, and represented 1,600 to 1,610 calories for a man of 72 kilogrammes (about 11 stone 5 lbs.) ; an insufficient figure, but the diet was a suitable one for a person who had to consume the fatty surplus of his own obesity. We may remark that a fasting man, during complete repose, *expends a minimum of 1 calorie per kilogramme-hour*, according to a mass of concordant observations.[1]   In Fletcher's case this would give a value of

$$1c \times 72 \times 24 = 1{,}734 \text{ calories.}$$

By this means Fletcher restored himself to a remarkable state of physical and moral health. During the whole of the year 1903 he consented even to become the subject of experiments conducted by the physiologist Chittenden, which were the basis of a very valuable survey of the question of hygienic and economical alimentation, and the origin of *Fletcherism*, for this singular person found many zealous followers. These latter discipline their sense of taste, gradually triumphing over the tyranny of the palate, by accustoming themselves to relish patiently masticated foodstuffs, which, turned over and over upon the tongue, stimulate the secretion of the digestive juices, and eventually become agreeable. Elaborate cookery is, justifiably, rigorously opposed. Fletcherism is merely a matter of training. Some will regard a rhythmical, calculated, regulated gymnastic of this kind as excessive in connection with the elementary act of mastication. There is a certain amount of truth in this, but I would gladly see it

[1] R. Tiegerstedt, *Arch. di. fisiol.*, Vol. VII., p. 426, 1909.

cure us of the opposite excess, of the *tachyphagia*, of which we are, at table, the often unconscious victims.

We will conclude by indicating the method of *evaluating* and *apportioning* our aliments, that is, of determining the rations proper to each according to his age and the nature of his work. In this volume, which is at once elementary and practical, I shall always be careful to refrain from giving advice impossible to follow. The best advice is that which respects the scientific truth and wins men to follow it. The chains of the laboratory must not too closely shackle the limbs of education, for education is a thing which lives and moves.

TABLE OF ALIMENTARY RATIONS.

(Number of calories per kilogramme of body weight per 24 hours.[1])

1. Light Occupations and Intellectual Work (authors, scientists, business men, officials, schoolmasters, clergymen, jewellers, tailors, dressmakers, etc.):

30 *calories* (macaroni, spaghetti, vermicelli, etc., fresh vegetables, milk, the more delicate kinds of fish, pastry, etc., to be given preference), of which proteid should form one-tenth.

2. Work of Medium Heaviness (skilled craftsmen, shopkeepers, hairdressers, dyers, chimney-sweeps, shop-assistants, domestic servants, etc.):

36 *calories* (same remarks as above; a moderate consumption of bread, and a very moderate consumption of meat—75 grammes [2·6 oz.]—daily; dried vegetables).

3. Fatiguing Work (soldiers, sailors, navvies, dock labourers, artisans, mechanics, labourers, agricultural and other, etc.):

50 *to* 70 *calories*, according to the amount of work performed (the above remarks apply; while bread, potatoes, and fruits, such as prunes, chestnuts, figs, grapes, raisins, etc., should be given, and not more than 200 grms. [7 oz.] of meat).

[1] In winter increase all these rations by one-fourth. Rations should be selected and apportioned according to the table which follows.

Table of Foods in Ordinary Use.[1]

Per 100 Grammes.	Carbohydrates.	Fats.	Proteids.	Calories.
Almonds, dried	18·00	54·20	18·10	641·23
Apples	14·41	0·06	1·44	65·53
Apricots, fresh	8·10	0·12	0·48	36·06
Artichokes, Jerusalem	13·07	0·21	3·68	70·00
Asparagus	4·72	0·41	3·38	36·94
Bananas	21·90	0·09	1·44	96·51
Beans, dried	54·41	1·32	27·32	347·38
Beef, sirloin	2·54	1·82	16·30	93·81
„ heart	2·20	4·84	15·25	155·59
„ suet	0·00	90·94	0·76	830·67
Brains, calves	0·12	16·33	13·26	203·26
Bread, home-made[2]	58·04	0·40	7·25	271·33
„ French roll	61·59	0·24	5·99	279·26
„ Viennese	57·29	0·11	7·03	264·71
„ Army[3]	53·58	0·10	8·05	254·14
Brussels sprouts	9·62	0·58	3·80	60·30
Butter	0·00	83·58	2·52	770·91
Carp	0·52	3·56	15·34	97·42
Carrots	9·50	0·19	1·19	45·56
Cauliflower, heart	4·89	0·38	3·51	37·90
Cheese, Brie	4·85	22·45	19·94	305·93
„ Camembert	5·95	21·65	18·72	298·16
„ Gruyère	1·79	26·95	36·06	400·43
„ Roquefort	3·00	38·30	25·16	464·00
Cherries, sweet	14·12	0·09	1·02	62·89
„ tart	11·97	0·40	1·26	57·88
Chestnuts, Limousin.[4]	33·16	0·89	2·47	154·18
„ large (marrons)	32·17	1·08	3·15	154·64
Chocolate, ordinary	62·65	25·50	8·35	523·10
„ Menier[5]	68·90	21·00	8·75	514·83
Cocoa (Congo)	30·25	42·40	11·35	556·40
„ (New York)[6]	37·70	28·90	21·60	506·12
Couscous[7]	85·40	2·07	9·80	409·16
Dates	67·10	0·06	1·96	283·69
Doura	52·50	0·44	8·33	253·40

[1] Unless otherwise stated these values are for fresh foodstuffs bought in Paris.

[2] Five days old.

[3] A. Balland, *Revue de l'intendance*, p. 361, 1907.

[4] These are Limousin chestnuts, the most abundant species; chestnuts form an important article of diet in many departments of France. The country produces about four million quintals (hundredweight approx.).

[5] Chocolate, made from the cocoa-bean, contains an alkaloid principle, *caffeine*, which is a neuro-muscular stimulant. According to our own investigations cocoa contains 0·16 per cent. of caffeine, while 100 grammes of *Chocolat Menier* contain 1 gr. ·40 per 100 grammes. American chocolate is very rich in fats, containing 26·80 per cent. of carbohydrates, 47·10 of fats, and 12·50 of proteids. Its calorific power is 589·74 (Atwater and Woods, *ibid.*). But the calorific power is no criterion of the quality of a foodstuff.

[6] According to Atwater and Woods, *Washington Bulletin*, no. 28, p. 41; 1896.

[7] Jules Amar, *Le Rendement de la machine humain*, pp. 50, 51, Paris, 1900. This value refers to the dried material; but the average amount of water contained in the freshly made dish is 58 per cent. It contains (in the dry state) ·735 per cent. of normal sulphuric acid. (See p. 221.)

Per 100 Grammes.				Carbohydrates.	Fats.	Proteids.	Calories.
Eggs, hens'	...	...	...	1·43	11·04	11·59	153·85
Endive	...	...	...	4·02	0·10	1·04	21·65
Figs, dried	...	...	...	53·67	2·10	2·26	248·42
Fowl, leg	...	...	...	1·16	10·95	17·19	174·58
Goose	...	...	...	0·58	18·85	14·24	232·30
Grapes	...	...	...	17·69	0·38	0·49	78·00
Gurnard, red	...	...	...	2·29	0·98	22·85	112·00
Ham (Potted)	...	...	...	0·73	33·83	18·60	387·10
Hare	...	...	...	2·55	3·34	29·88	163·36
Haricot beans, fresh	...	...		4·17	0·28	1·99	27·86
„ dried	...	...		53·68	1·44	20·18	315·93
Herrings, fresh	...	...		0·46	4·80	17·23	116·21
„ kippered	...	...		0·71	14·97	51·62	350·74
Hazelnuts	...	...	...	13·22	61·16	15·58	674·64
Horseflesh (steak)	...	...		1·44	2·95	21·95	122·74
Lentils, dried	...	...	...	56·07	1·45	23·04	337·55
Lettuce (Cos)	...	...	...	1·74	0·15	0·92	12·27
Liver (calves')	...	...		1·83	7·13	19·12	150·78
Macaroni[1]	...	...	...	75·70	0·65	10·89	361·02
Mackerel	...	...	...	0·28	15·04	15·67	202·26
Melon (Canteloupe)	...	...		3·72	0·11	0·60	18·71
Milk (cow's)	...	...	...	4·83	4·12	3·23	70·54
Mushrooms	...	...	...	3·68	0·32	4·50	36·45
Mutton (leg)	...	...	...	2·36	6·53	17·86	142·32
Oysters	...	...	...	7·33	1·43	8·70	78·84
Peaches	...	...	...	10·36	0·48	0·86	50·37
Pears	...	...	...	9·93	0·04	0·24	42·06
Peas, green	...	...	...	14·02	0·24	4·47	78·00
„ dried	...	...	...	57·76	1·40	20·56	335·85
Pork (leg)	...	...	...	1·58	3·10	20·30	117·92
Potatoes	...	...	...	17·58	0·04	1·71	79·45
Prunes (pulp)	...	...	...	71·44	0·40	2·37	306·26
Rabbits (leg)	...	...	...	0·77	3·14	23·49	126·81
„ (loin)	...	...		1·90	1·97	18·66	102·22
Raisins	...	...	...	76·70	0·56	0·45	313·41
Rice, white	...	...	...	75·22	0·30	8·89	347·58
Salmon	...	...	...	0·08	20·00	17·65	254·69
Sardines, fresh (pilchards)	...			0·57	2·33	22·12	114·23
Sole	...	...	...	1·11	0·81	17·26	82·69
Spinach	...	...	...	5·58	0·33	4·06	42·53
Skate	...	...	...	0·17	0·45	22·08	95·32
Strawberries, wild	...	...		8·85	0·99	1·36	50·87
Tomatoes	...	...	...	2·92	0·10	0·89	16·53
Turnip	...	...	...	5·57	0·06	0·47	25·31
Tripe	...	...	...	4·73	16·79	19·06	250·33
Veal (round)	...	...	...	0·92	2·28	20·40	108·16
„ (fillet)	...	...		1·22	4·08	22·27	138·43
Vermicelli (ribbon)	...	...		75·21	0·60	11·58	361·30
Walnuts	...	...	...	17·57	41·98	11·05	499·36
Whiting	...	...	...	1·25	0·46	16·15	75·53

[1] The various farinaceous pastes—macaroni, spaghetti, vermicelli, semolina, etc.—have much the same composition.

XLIII. Observations, and Particular Cases.—As a general rule, it is a good thing to ensure that *vegetable foods* shall predominate in our diet, without employing them exclusively ; for instance, we should not exclude eggs, milk, and the lighter fish (sole, whiting, gurnard, and fresh-water fish).

Great care will be taken that the aliments are of good quality.

Restaurants and eating-houses should be subjected to a very strict inspection, for the working-classes are particularly exposed to the *frequent* consumption of stale or spoiled food-stuffs, to the detriment of their health. Cheapness should never be made an excuse for fraud, and here least of all.

The *child*, after the period of *suckling*, must eat freely, on account of his *growth*. He will always thrive best on mother's milk ; otherwise he should be given cow's milk, boiled, and slightly diluted with a 10 per cent. solution of lactose. Then pap and bread and milk will be given, and at the age of 18 months meat broths, finely minced chicken, mashed potatoes, and sweets. At this age, as later in the case of the adult, the bodily weight should be kept under inspection ; in the adult it should be constant, while in the child it should steadily increase. But the treatment of the *nursling* requires competent supervision ; in cases of anaemia, dyspepsia, or intestinal catarrh a specialist should be consulted without delay.

Between the ages of two and nine to ten the child absorbs 90 to 70 calories per kilogramme, or two to three times as much as the adult. One cannot without danger reduce the child's consumption of food, nor his activity, for his organs are undergoing formation, and are learning to perform their functions. Limitation is not education.

On the further slope of life, in the *aged*, the digestive function becomes enfeebled, and the expenditure of energy gradually diminishes. Care must be taken to avoid fatiguing the gastro-intestinal organs, and to provide them with easily digested foods ; farinaceous foods, such as macaroni and vermicelli ; very tender white meats, fresh vegetables, and stewed fruits. Sobriety is a necessity in old age ; a sobriety which should extend to all causes of excitation, in order

that the cerebral system shall not be unduly tried. The economical use of food and stimulants prolongs the life. We may cite the well-known example of the Venetian gentleman *Luigi Cornaro* (1464–1566), who carried alimentary economy to the verge of parsimony, and at the age of 94 preached his doctrine in a volume " full of wit and common-sense " : [1] *Metodo di vivere a lungo*, with the sub-title *Discorsi della vita sobria* (Padua, 1558). An invalid until his fortieth year, having abused his constitution, he succeeded in completely re-establishing his health, and in dispensing with medicine of any kind, thanks to the regimen which he imposed upon himself. When almost a centenarian he even took part in a lawsuit, which caused him great annoyance, without affecting his health ; more, he fell out of a carriage, but the fall left no traces. " Which plainly shows," he writes, " that neither melancholy, nor the passions of the mind, are able to produce unpleasant results in those who live according to rule—and that the majority of accidents should not be very dangerous " (*Loc. cit.*, pp. 49, 53).

It does not enter into our scheme to deal, even in passing, with the question of diet, or the science which adapts the diet to the state of health. The science of dietetics stands, as it were, at the cross-roads of physiology, pathology, and therapeutics ; it must not be degraded to form one of the departments of the culinary art. The moment a sick man has received competent advice to carry out a given regimen, he should do his utmost to submit to the latter. Order and proportion govern the whole universe. It would be a singular pretention to seek to liberate our vegetative life from their empire !

XLIV. **What to Drink.**—Alimentation, in the true sense of the word, comprises the liquid part of our diet, a very large portion of which is represented by the fluids which enter into our foodstuffs.

[1] From an appreciation by Joseph Addison in the *Spectator* for 13 October, 1711 (see the Introduction to the English translation of Cornaro's book, *The Art of Living Long*, p. 21, 1903).

Water is incontestably and *par excellence* the natural hygienic beverage, for it is one of the constituent elements of all living creatures. We too often forget that the *end* of drinking is a physiological end, which no liquid other than water can accomplish ; the organism strives to maintain an *invariable degree* of hydration.[1] Further, the water drunk must be wholesome, neither containing salts nor infected with microbes. *It is always best to boil it and to let it stand for twenty-four hours in the cellar.* It is then free from all contamination, and one may be certain of having a water *agreeable to the taste.* On the other hand, water favours the digestion, and in particular the digestion of fats and carbohydrates.[2] It infallibly quenches the thirst, for *thirst* is sensation resulting from a deficiency of water, just as the *appetite* is a sensation announcing *hunger*, or the need of food. Both sensations originate in a derangement of the dynamic condition of the cells, which results in a disturbance of the nervous system.

The custom has unfortunately prevailed of regarding *alcoholic liquors* as the equivalents of water ; and almost everybody makes use of them. This is an absolutely mistaken attitude. Alcohol is above all a fuel ; it yields more than 7 calories per gramme ; if taken in doses of 50 to 60 grammes *per diem* it will supply the organism with heat, and will in part do the work of the ordinary foodstuffs in this connection. But it should *never* be regarded as an immediate source of increased energy, whether mechanical or intellectual.

Above all we must not lose sight of the *toxic effects* of alcohol. The nerve-cell is particularly sensitive to these effects. Wines, beer, and cider produce such effects by reason of the alcohol which they contain ; but spirituous liquids add to these toxic effects the terrible effects of the *stupefying ethers* and essences which enter into their composition ; and their sale— like that of absinthe, now absolutely forbidden in France, thanks to the enlightened zeal of M. Ribot—should be prohibited, or at least restricted. The other alcoholic drinks

[1] Terroine, *Comptes rendus Biologie*, 28 March, 1914.

[2] Mattill and Hawk, *The Journ. of the Amer. Chem. Soc.*, Vol. XXXIII., p. 1,978, 1912.

I

may be permitted without serious danger, provided their daily consumption does not exceed, say, *half a litre of wine* (·88 of a pint, or about 17½ oz.) or a *litre of beer or cider* (1·76 pints, or about 35 oz.). A hygienic doctrine which should recommend such principles would be understood by all, and would in the long run triumph over the hideous evil known as *alcoholism*.[1]

XLV. The Effects of Alcoholism.—It may be as well to describe the ravages of this disease. "The best means of insuring oneself against drunkenness," said Anacharsis the Scythian, a Greek philosopher of the sixth century B.C., "is to represent to oneself the *degradation of drunken persons.*"

I will say nothing as to this moral deterioration ; but what of the physical ! The entire *digestive system* is irritated ; its secretions accumulate ; gradually irritation gives way to an ulcer which perforates the stomach. The "morning phlegm" is the first symptom of this degenerative process. Kyrie and Schopper[2] have stated that the alcohol of wine, employed in doses of 100 *to* 110 *grammes daily*, causes gastric ulcerations, with congestion and degeneration of the liver, finally leading to *hepatic cirrhosis*. The liver, that storehouse of glycogen, from which the muscles are revictualled by means of the blood, and which assists in the production of the heat of the organism, is profoundly impaired ; it becomes hard and fibrous, and ceases to fulfil its manifold functions.

And the *circulatory system?* Alcohol has a depressing action on the heart ; the contractile power of this organ rapidly diminishes ; it can no longer exert its normal effort, nor its ordinary capacity for work ; the nervous mechanism regulating its action is paralysed as soon as the dose reaches 2 grammes per kilogramme of body-weight[3] ; the frequency of the heart-beats diminishes, and the depressing effect is revealed by a prolonged diastolic pause.[1]

[1] I have given all the arguments, whether of fact or of doctrine, on which my conclusions are based, in *Le Moteur Humain*, pp. 198, 283 and 596.

[2] Pentimalli and Di Christina, *Archiv. di Fisiol.*, Vol. VIII., p. 131, 1910.

[3] Kyrie and Schopper, *Arch. f. Path. Anat. u. Phys.*, Vol. CCXV., p. 309, 1914.

[4] Chistoni, *Arch. int. de Physiol.*, Vol. XIV., p. 201, 1914 ;—Galleotti and Di Jorio, *Arch. di. Fisiol.*, Vol. XII., p. 401, 1914.

Degeneration of the heart may result in death ; the blood-vessels, moreover, become less elastic, and their rupture is of frequent occurrence : hence disastrous haemorrhages. In this connection we observe, as on the confines of old age, a degeneration of the tissues—a sclerification, giving rise to arterio-sclerosis. The observations of Lian[1] have established that all heavy drinkers suffer from *arterial hypertension*.

Lastly, the *nervous disorders*. Lussana, who experimented with doses averaging 2 grammes per kilogramme of body weight, found that the tonicity of the muscles and the reflexes was enfeebled, a result due to nervous depression.[2] And if the presence of alcohol in the organism is sought for, it will be found that it localises itself, by preference, in the brain and the *medulla oblongata*, finally arresting the respiration and producing asphyxia.[3] The alcoholic subject frequently dies suddenly, and from asphyxia.

Other manifestations of alcoholism are observed, the most familiar of which are : the characteristic trembling of the hands, headaches, vertigo, cramps, hallucinations of the senses, nightmares, and above all, *delirium tremens*, a violent crisis in which the conscience disappears, rendering the man capable of any crime. Even when he is still far removed from this acute stage, the control of his sensations and the association of his ideas are far less assured than usual ; the mind wavers ; there is moral and physical deterioration.

The alcoholic offers little resistance to infectious maladies ; it is on him that *tuberculosis* takes its firmest hold ; and in him accumulate all the morbid taints and germs which, by an inevitable physiological law, he will transmit to his descendants[4] ; his children, weakly, atrophied, or insane, die at an early age. Had not the first legislators this law of heredity in mind when they announced that God would punish the transgressor even to the third and fourth generation ?

[1] C. Lian, *Bull. Acad. de Médecine*, 9 November, 1915.

[2] Lussana, *Arch. di Fisiol.*, Vol. X., p. 269, 1913.

[3] Sabbatini, *ibid.*, Vol. VII., pp. 49-80, 1909.

[4] Stookard and Papanicolaou, *The American Naturalist*, Vol. L., February and March, 1916.

The alcoholic is incapable of work which demands attention, delicacy of touch, and precision of movement. If he is wounded, if he breaks a bone, his recovery is slow and difficult. He becomes a charge upon society much more readily than the sober man. How should society not treat him with disdain?

Concerning the organisation of the struggle against alcoholism and tuberculosis, see a capital article by Albert Robin,[1] and a very interesting discussion between Chauveau and Landouzy.[2]

XLVI. **Physiological Conditions.**—The organisation of labour is founded on *individual aptitudes* and the general condition of the organism (see Chapter II). An attentive medical examination will enable one to discover whether the vocation which the subject intends to follow is in accordance with his physiological resources. *Intellectual labours* and those demanding *rapidity of movement* exhaust the cerebral energy, especially when protracted. Thinkers whose health is poor, whose nervous potential is low, are obliged to interrupt their work by frequent intervals of repose, and to avoid lengthy tasks; the connection to be established between their ideas, and the proportions to be maintained between the parts of an immense and complex whole, would compel them to exert an effort of attention of which they are not capable. If they persist in such an effort, disorders of the sight or hearing, or the impatience of the *neurasthenic*, warn them of the danger, *neurasthenia* being merely a form of nervous exhaustion. In manual occupations these disorders affect the co-ordination of the movements : the sportsman and the athlete are no longer sure in their movements ; typists, shorthand-writers, and compositors " drop their words " ; dressmakers miss their stitches. Their sensitiveness, generally exquisite, cannot be replaced by determination ; there must be organic fitness. Alcoholics, accordingly, should be absolutely excluded from such pursuits. I might say almost as

[1] A. Robin, Bull. *Acad. Med.*, 15 July, 1913.
[2] A. Chaveau, *C. R. Acad. Sciences*, Vol. CLXII., pp. 855 and 932 ; June, 1916 ; L. Landouzy, *ibid.*, pp. 903 and 967.

much of anaemic subjects. In branches of labour which entail the exertion of great strength sprains, dislocations, cramps, and lacerations of the muscles are of fairly frequent occurrence ; so that a robust constitution is requisite, exempt from any defects which predispose one to accidents. *Alcoholics* are not fitted for such work ; in them the muscles of the heart are debilitated, and liable to failure, which leads to syncope ; nor are *diabetic* subjects, for their muscular force is diminished by at least fifty per cent. ;[1] nor those suffering from declared *tuberculosis*, nor ruptured persons, etc. It is obvious that those who have been wounded in the war, or have suffered injury in industrial accidents, but particularly the former, should be subjected to an examination which will compute the degree of their physiological resistance to fatigue.

Neither women nor minors who have not attained their *eighteenth year* should be allowed to undertake *heavy work*, for they have not the necessary strength, their musculature being insufficient. Women are weakened by *menstruation* and by *pregnancy ;* the pains and the lassitude in the loins and legs persist for four or five days after each menstruation ; while as a result of pregnancy the womb invades the space beneath the diaphragm, compresses the heart, and diminishes the volume of the respirations.

The thoracic muscles are in a state of unnatural contraction, which results in an actual condition of permanent fatigue, and there is also a slowing-down of the processes of nutrition. During this period an industrial environment is highly pernicious, for pregnant women are highly sensitive to toxic substances and infectious germs,[2] which, passing from the body of the mother to that of the child, result in the deterioration or death of the latter. Here, if ever, social hygiene may profitably display its foresight, by organising prophylaxis and preparing the race to resist disease.

Finally, attention should be given to the condition of the *senses*, which are rarely perfect. The sight of the *myopic* should be corrected, so that they need not stoop over their

[1] Ducceschi and Albarenque, *Archiv. di Fisiol.*, Vol. VIII , pp. 589-600, 1910.
[2] Lewin, *Berl. Klin. Wochensch.*, p. 701, 1905.

work ; otherwise the body will become misshapen, acquiring the " scholar's stoop," and will be more subject to fatigue. The horizon of the myopic subject is limited ; the concave lenses seem to enlarge and illumine it ; the worker modifies his attitudes, corrects his movements, and shows a better appreciation of the *relative proportions* of objects. This correction is indispensable in the case of jewellers, engravers, compositors, authors, scholars, etc.

Colour vision must be investigated in the case of painters, decorators, dyers, railwaymen, etc. Those who neglect this precaution may encounter many causes of mortification.

The sense of *hearing* gives the worker his normal demeanour, as it gives the singer his note and the orator his tone. It marks the rhythm of speech. It also regulates the movement of tools whose action is periodical—planes, saws, files, etc. Blacksmiths and navvies, for example, strike with their hammers in such a way that the latter do not clash with one another. *Bi-auricular* hearing helps us to locate the origin of sounds with accuracy ; it is, moreover, far more sensitive than the hearing of one ear only.—Finally, in some professions it is important that those who follow them shall possess an acute sense of smell. Such are pharmacists, vintners, oil merchants, cooks. The sense of smell may be refined by practice, just as it becomes fatigued by the continual influence of odours (as in the case of leather-dressers, sewermen, etc.).

We might refer further to the sense of *touch*, but of this we have already spoken, and we shall return to it when dealing with the problem of the *blind ;* so that we may now conclude this brief survey of the internal factors of human activity.

XLVII.—B. External Factors of Work : The Atmospheric Environment.—For the same reason I shall be sparing of details of the external factors, the chief of which is the *temperature of the air.* When this temperature falls, the respiratory exchanges are stimulated, and the production of heat increases, enabling our bodies to remain at their normal thermal level. It is by the intervention of those contractions of the

cutaneous muscles which we know as a *shiver* (Ch. Richet) that this phenomenon of extra stimulation is produced. It originates in a peripheral reflex.[1] As the external temperature rises we have less need of this thermogenesis. At 20° Cent. (68° Fahr.) the organism enters the zone of indifferent temperatures, and the minimum of respiratory exchanges corresponds with a temperature of 27° to 28° Cent. (80·6° to 82·4° Fahr.).[2] But having regard to the contractive effort of the muscles, one cannot, without greatly diminishing this effort, labour in an environment heated above 18° Cent. (64·4° Fahr.). In summer, or in hot climates, the muscles contract swiftly, but are incapable of sustained action ; it is the muscular fibre itself which is debilitated, for the nerve-centres are little affected by temperatures between 95° and 104° Fahr.[3]

The toxic waste products become abundant ; they exist in the blood, the perspiration, and the urine. It then becomes necessary to cleanse the interior of the organs by a moderate vegetarian diet and by the use of beverages in which water predominates, and at the same time to cleanse the exterior of the body by washing the surface of the skin thoroughly and frequently.

In *winter*, or in *cold climates*, the movements are languid, slow, but capable of sustained action ; the nervous reactions lack vivacity, and eventually the worker does not properly co-ordinate his movements, and modifies or controls them without delicacy. I have noted in many workshops that the best work is obtained in a temperature of 13° to 14° Cent. (55·4° to 57·2° Fahr.), when the buildings are spacious and well ventilated. Offices and living-rooms should be heated to 17° to 18° Cent. (62·6° to 64·4° Fahr.). For persons whose work keeps them motionless, the temperature of the air should not fall below 62·4° Fahr.

The atmosphere subjects us also to various other influences : *barometrical pressure, hygrometrical conditions (humidity or*

[1] Sjöström, *Skand. Arch. f. Physiol.*, Vol. XXX., p. 1., 1913.

[2] Ignatius, Lund, and Wärri, *ibid.*, Vol. XX., p. 226, 1908.

[3] Broca and Richet, *Arch. de Physiol.*, p. 871, 1897.

dryness), *aerial currents, dust, etc.* The inconveniences resulting therefrom are manifold. In weaving-sheds and spinning-mills it is important to alleviate the heat and humidity by the use of proper ventilating apparatus; otherwise serious symptoms will make their appearance; the perspiration being diminished in the warm, saturated atmosphere, there results a retention of toxic substances in the blood, a process of slow poisoning, which is betrayed by the anaemic aspect of textile operatives, and their diminished resistance to infection.

The influence of *barometrical pressure* and of *altitude* is also interesting; but it is a complex question, for which we must refer the reader to our volume on *Le Moteur Humain*, pp. 322–332. The cold adds its effect to that of the altitude; the organism is weakened thereby; and while the heart remains normal, with a constant arterial pressure,[1] we find that the muscular force is diminished, while the nerve-centres function irregularly.[2] An engineer has even stated that " at an altitude of 5,000 metres (16,250 ft.) a mine of golden sovereigns all ready minted would hardly be exploitable."

We must also mention the case in which work is done in *compressed air*, as in diving-bells, caissons, diving-dress, boring-shields, etc. Working under such conditions often gives rise to " caisson disease." The respiration slows down; the compressed air is dissolved in the blood in greater volume than usual, and when decompression occurs it leaves the blood, being liberated into the cellular tissue. The results are itching, pricking pains, and sometimes tumefactions. The most dangerous moment is that of emerging from the caisson. " One pays only on leaving," as the French proverb has it. Gaseous embolisms are more frequent and more dangerous in fat subjects; they may be fatal.

On diving there is a *ringing* in the ears, sometimes accompanied by pain, which disappears upon the act of swallowing. During work a certain difficulty of movement is experienced, with a feeling of rigidity in the joints.

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[1] Guillemard and Regnier, *C.R. Acad. Sc.*, 8 November, 1913.

[2] A Mosso, *Fisiol. del uomo sulle Alpi*, pp. 7, 11, Milan, 1897 (2nd ed., 1910).

Lastly, the arterial pressure increases by 1 to 3 centimetres, denoting an excessive cardiac effort; and there is a marked tendency to fatigue. The blood presents the characteristics of anaemia; there is a diminution of the number of red blood corpuscles, and of the amount of haemoglobin, which persists after work has ceased; these are indications of a certain derangement of the *haematopoiesis*, or the process of blood-making.[1]

XLVIII. **Clothing**.—We protect ourselves from the effects of temperature by covering our bodies more or less thoroughly; but we are ill protected against the variations of atmospheric pressure and humidity.

The choice of *clothing* should satisfy a threefold condition: it should protect the body from the cold, or the heat of the sun, should permit of a ready cutaneous transpiration, and should leave the limbs their full liberty.

Wool is by far the most hygienic material for clothing; still, in summer one may have recourse to white *flannelette*, which absorbs the solar rays with difficulty, and prevents a too rapid evaporation of the perspiration. Workers who are employed on the heavier kinds of physical work would do well always to wear woollen clothing, more or less light in quality. The belt should be replaced by elastic braces, and no tight garments should be worn to impede the circulation and respiration; a tightly buckled belt makes sustained effort difficult, and diminishes the thoracic expansion. We need hardly add that cleanliness of clothing is conducive to the health of the wearer, while it shows that he is careful, heedful, and orderly.

XLIX. **Entertainments — Amusements — Rest**.—Many are the factors which cannot be mentioned in this survey, but which favour or impede human activity. But I should like to say a few words as to *amusements*. They are useful; they are even necessary; in the uniformly hard life of the worker they are actual nervous restoratives; the stimulations which they

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[1] Solovtsov, *Rousski Vratch*, Vol. XIII., pp. 511, 616, 1914.

afford the *senses* cause a reinforcement of the motor reactions. If, as has been proved by experiment, these stimulations are sometimes disagreeable and inhibitory, the worker avoids them. Consequently any good performance or entertainment which is of good quality, and wholesome, constitutes a factor of work. A *recreation-room*, close to the workshop or factory, is soon paid for by the increased production which results from the contented spirit of the workers.

Here the daily hours of rest will find excellent employment. And I imagine that the working-man will form a habit of devoting a portion of his weekly rest to instructive and recreative walks, or merely to amusements ; the rest being devoted to the affairs of domestic life ; to his family, to his home. If he regulates his life, if he has a little method, these last occupations will not occupy him long, nor weigh heavily upon him ; so that the weekly holiday will be what it ought to be, humanly and physiologically; a *rest*, which repairs the organism, a veritable truce with fatigue. How many so understand it ? It would not be difficult to count them.

L. Equipment and Labour.—I will remark, in conclusion, that the very conditions of muscular work, regulated as to effort, pace, and hours of labour, are also properly external factors—and the most important of external factors. However, we have considered them at the beginning of this chapter. There remains the question of equipment. It is very obvious that every worker should get together a stock of tools adapted to the nature of his work, selecting the best, and that he should adopt the attitude which involves the least fatigue. It is the same whether he reads and writes, sews and embroiders, or observes and experiments. It is particularly important in the case of the working-man, and most important in that of the wounded man, the cripple, who is to be *re-educated* or *re-adapted*. There are three conditions which should be realised :

To arrange the workshop or factory in such a way that there is no loss of time or energy.

To determine the shape, the quality, and the pace which

will ensure the maximum output from the plant, and to favour the introduction of machinery.

To fulfil, in the workshop, the conditions of lighting and ventilation which make for normal activity.

I will illustrate these principles by an example drawn from the *Art of the Mason*, specially worked out by Gilbreth : [1]

1. Is the bricklayer left-handed ? The position of the bricks and mortar will be changed, in order to facilitate his movements.

2. The hods of bricks will weigh from 27 to 40 kilogrammes (about 60 lbs. to 90 lbs.) according to the strength of the hodman ; the hammer for breaking material will be 4 lbs. in weight, and the hammer for shaping 4·3 lbs. ; the spade for shifting materials will be $21\frac{1}{2}$ lbs. in weight, and two different trowels will be provided for ordinary bricks and agglomerate bricks.

3. Bricks and mortar will be arranged by an assistant within reach of the bricklayer, so that he is able to seize the brick by a natural movement, which makes use of gravity, and not by a constrained movement ; above all, so that he does not need to stoop or move from his place or sway his body in one direction or another.

4. The mortar which is dropped during work will not be picked up ; a bag of cement will not be opened by tearing the paper and separating the various thicknesses ; the paper will be cut open by a blow of the spade, at the base of the bag, and the latter will be emptied by jerking the other end of it. Lastly, it costs less to use good cement to fill a gap less than half a brick in width than to break a brick or to look out a piece to fill the gap. [2]

To these measures, which simplify and accelerate the worker's task, we must add such as economise his efforts, whether this involves a new implement, enabling him to do the work without fatigue, or the use of perfected machinery, whose control is mere play to the worker. When we think of the great number of weak and mutilated workers who would

[1] F. Gilbreth, *Motion Study,* 1911.
[2] For details see *Le Moteur Humain,* pp. 579-583.

find, in such a transformation of the technical instruments of work, the means to make themselves useful, and to earn a secure living, one can but hope that such innovations will be made in our industries, which are, unfortunately, slow to shake off the yoke of routine.

These few hints will enable the reader to appreciate the importance of a rational organisation of the technical instruments of work, and of the workers, and of the economy thereby effected, and the lessons which it so abundantly teaches. Without such organisation the *art of labour* would not exist, and this art is the source of all prosperity.

CHAPTER VI

THE ART OF LABOUR

PHYSICAL ACTIVITY

LI.—The modes of human activity are infinite. They must be analysed into their constituent elements—*mechanical, physiological, and psychological*—in order that we may effect all the improvements desirable in each of these spheres.

The most urgent task of social reform is precisely to investigate the means of developing, and devoting to useful ends, our human resources of energy. This task is one which concerns the economist, the engineer, the legislator, the physician, the parent, and the teacher, for its aspects are *social energetics*, *manual craftsmanship*, and *physical education*.

The activity of man is *one* as regards its essential laws, but its forms and aspects are varied, as are its applications. We shall consider these only so far as will enable us to take a rapid survey of them.

LII.—A. **The Handicrafts. Examples—the use of the file and the plane.**[1]

A fair idea may be obtained of the method underlying our efforts by the following example, relating to the use of the *file*. As we have already explained, the tool is equipped and connected with appliances which make a direct record of all the efforts exerted by the worker. These give, in a *graphic* form, the path and the speed of his movements, a precise idea of their regularity or their defects, and the amount of muscular force expended.

Jules Amar, *Journal de Physiologie*, p. 62, 1913.

On the other hand, the *energy* which the organism devotes to the work performed is estimated in calories, very exactly, by measuring and analysing the respiratory exchanges. The apparatus employed is shown in Fig. 45, where we see a young apprentice using the file. It will be noted that the mouth-
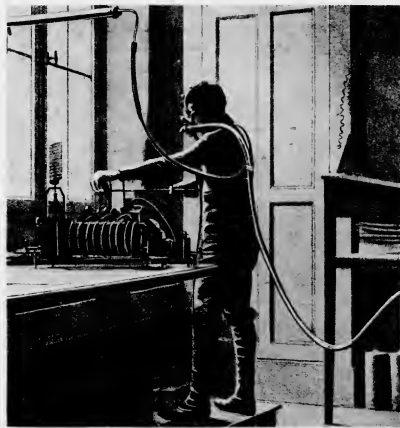

FIG. 45.—An Apprentice using the File. Method of estimating Fatigue.

piece of the respiration gauge is supported by a metallic band which fits over the crown of the head. Pure air is supplied from without by means of a flexible tube, and the gases expired are collected in a gauge, from which a sample is taken later on for analysis. Tried first, and many times, upon myself, this method has for ten years given proof of its simplicity and reliability. During that time it has been applied

to about a thousand persons—Parisian working-men, soldiers, and natives of North Africa. It is therefore of universal applicability, and, for that reason, eminently scientific.

The use of *large metal-workers' files,* when investigated on the lines already explained, has proved to be one of the most interesting subjects for consideration. If the man who handles the tool is a *good workman,* skilful and well trained, we find that graphic analysis furnishes us with regular curves, which are obtained without an excessive expenditure of force ; the muscular action is uniform and disciplined, while the respiration is regular, as we may see by the tracings in Fig. 25 (p. 72).
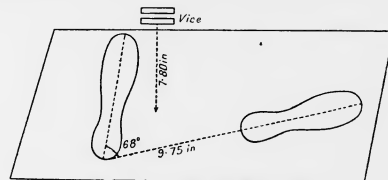

FIG. 46.—Economic Attitude of Man filing Metal.

By correcting the trifling defects of attitude displayed by the worker, as well as his conventional or rule-of-thumb habits, in the light of the results of our dynamic and energetic measurements, we have been able to determine the normal position of the feet, the proper distance of the body from the vice, vertically and horizontally, and the positions of the hands with regard to the tool (Fig. 46). When these conditions are fulfilled the worker's fatigue is diminished without injury to his daily output.

We may note, in Fig. 25, the great regularity of the work, the truly horizontal action of the file being represented by uniform curves, while the return strokes are, as they should be, effortless ; the subject, moreover, is working at a normal pace, the stroke of the file utilising the whole working length of

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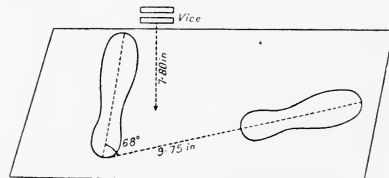

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the tool. After eight months of experiment and investigation we succeeded in working out the laws of the maximum of production with the minimum of fatigue, the metal being brass, and the file a " half-rough " tool 35cm. (about 13¾ in.) in length.

" The body of the worker should be vertical, but without rigidity, at a distance of 20 cm. (about 8 ins.) from the vice, the latter being at the level of the navel ; the position of the feet should be as follows: the angle of divergence, 68° ; the distance between the heels, 25 cm. (10 ins.) ; the left arm should be completely extended, and should press upon the tool rather more heavily than the right arm, their respective efforts being 8·5 and 7·5 kilogrammes (18¾ and 17½ lbs.). The return stroke of the file should consist of a simple sliding movement, without pressure. Finally, the rhythm of the movements is 70 per minute.

" All these conditions being fulfilled, 5 *minutes' work will be followed by* 1 *minute's complete repose,* the arms falling to the sides.

" The respirations and the heart-beats then undergo an average increase of not more than 25 and 20 per cent. respectively, in comparison with the figures obtained during repose. The local fatigue of the right forearm is endurable, while general fatigue is hardly perceptible. The maximum output is at least double the ordinary output of the great majority of workers."

In this particular case 600 grammes (1·32 lbs.) of filings were removed per diem, the day consisting of 7 hours' effective work.

LIII.—APPRENTICES.—In addition to this ideal output, we should determine an average output, that accomplished by the majority of workers who know their trade, and are normally constituted. This varies little. It is found to correspond with the graphic records of similar regular efforts. We find, in fact, that muscular action is exercised in the same fashion, and yields the same analysis, or almost the same, in all these men, when they are employing the same tool. It varies only

in its absolute value, principally because the worker is lacking in skill ; or above all, because he is a beginner.

But in the case of *atrophy of the muscles,* or *functional weakness,* which diminishes the strength and the play of the limbs,
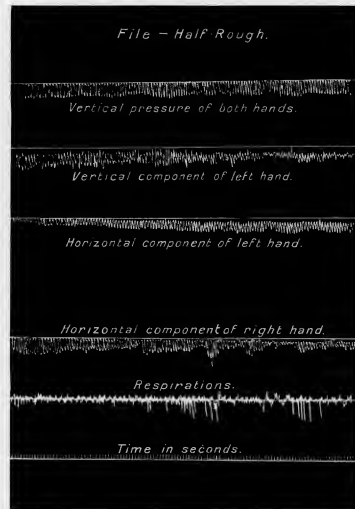

FIG. 47.—Graphic Records of the Work of an Apprentice filing Metal.

the tracings became *irregular,* the action of the muscles being unequal and obviously abnormal.

In the case of a beginner who is handling a large file, the muscular efforts are considerable, unequal, ill-directed, and too

K

sudden. At the end of two minutes the young man is out of breath; his respirations are irregular, proceeding by fits and starts (Fig. 47); it is extremely interesting to compare them with those of a good workman. An enforced halt becomes necessary, which is not the intentional and restorative period of repose; the wastage of energy amounts to 66 per cent. of the best output.

The apprentice seems to hurl himself upon the vice; he leans his body forward, and erects it again on the return stroke of the file; these oscillations of the body exhaust him, the more so because, in order to put a swing into the forward stroke of the tool, he places his feet incorrectly, lacks equilibrium, and, in a word, annuls a portion of his efforts. When one comes to take a *cinematographic photograph* of the beginner at the work-bench, his oscillations and ill-controlled movements are strikingly revealed. As a rule the so-called instructor, when correcting a beginner, advises him to hold himself erect and rigid. Now this absence of elasticity results in fatiguing contractions of the muscles of the trunk; moreover, it produces an awkwardness, a *gaucherie*, which is a common fault of beginners. The classic apprenticeship is not without a certain amount of blockish stupidity.

We have, for purposes of demonstration, trained an *apprentice*, a boy of 15, with the help of the graphic method. He himself was able to read, in the irregularity of the tracings obtained, the effects of his inexperience, and to correct himself accordingly; he assured himself, by the weight of filings removed hour by hour, of the truth of the scientific principles of craftsmanship; and, apart from personal instruction, he received a veritable object-lesson to the effect that the intelligently trained workman performs more useful work and squanders less of his strength. This was proved by the dynamographic curves and the figures relating to the consumption of oxygen.

Having illustrated the ideas already expounded by this example of work with the file, we need not analyse in detail the elements of the work performed by the joiner using the jointing-plane (Fig. 48). Here again we have a periodical

action, a to-and-fro movement involving a determined effort and rhythm. As has already been explained, the
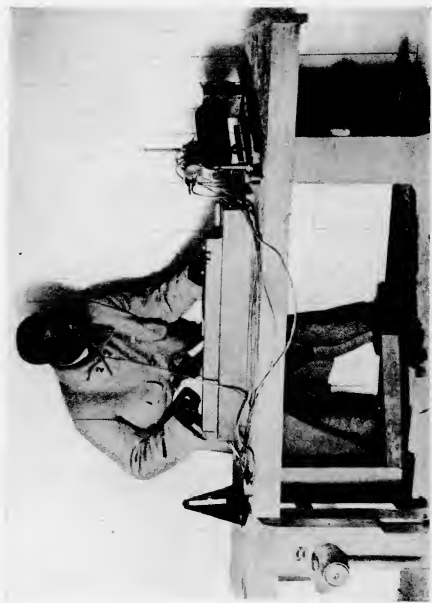

FIG. 48.—A Martinique Soldier working with the self-registering Jointing-plane.

apparatus employed makes it possible to discipline the movements and to direct them properly. The efforts exerted are likewise disciplined, by the employment of a simple device;

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FIG. 48.—A Martinique Soldier working with the self-registering jointing-plane.

apparatus employed makes it possible to discipline the movements and to direct them properly. The efforts exerted are likewise disciplined, by the employment of a simple device ;

an electrical circuit, containing an electric bell, is closed by the inscribing stylus and a contact-piece, thus enabling us to limit the pressure of the hand to 5, 10, or 15 kilogrammes (11, 16½, or 22 lbs.), as the bell is heard the moment the selected limit is exceeded. In this manner the apprentice can check himself,
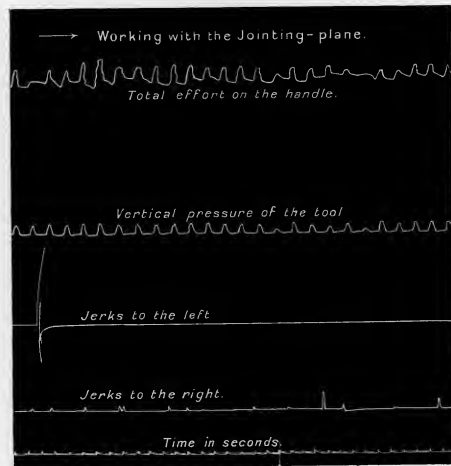

Fig. 49.—Records made by a Joiner's Apprentice.

and can even acquire, in a very short time, a *sense of effort*, and a notion of *uniform work*. If the plank which he is planing is changed for one of a different kind of wood, he perceives that his effort encounters a different resistance, and he quickly gains experience of the value of his tools. The total pressure on the handle, in the case of a jointing-plane in good order,

amounts, on an average, to 25 kilogrammes (55 lbs.) and the pressure on the wood to 12 kilogrammes (26·4 lbs.). From this it follows that the resistance encountered by the iron of the plane is equivalent to 22 kilogrammes (48·4 lbs.). The muscles of an apprentice or a wounded man may be overtaxed by protracted exertion of this kind. But it is evident that a number of factors go to modify the degree of strength required for such work (the nature of the wood, the thickness of the shavings, etc.), the most important of these being technical instruction (Fig. 49).

LIV.—The Case of those who are incapacitated from Labour.—Very different are the conditions of activity in the case of persons who suffer, in any degree whatsoever, from a *functional incapacity*, or from *mutilation*. We are speaking of the victims of *industrial accidents*, and the numerous workers who have been *crippled* as a result of *wounds received in battle*. This question we shall consider later on. But we would lay stress upon the *pedagogic* function of the foregoing method, in re-educating and re-adapting all these wounded soldiers, in determining the degree of physical diminution which they have suffered, and in guiding them to the choice of a trade.

Apprenticeship, in any case, demands a re-education in the light of the data obtained by experiment.

LV.—The Carrying of Burdens.—In 1907 we had occasion to study the *carrying of burdens* on the lines of the method which we have just explained.[1] Hundreds of workmen and soldiers were placed at our disposal during a period of several months. We will indicate only the results obtained :

1.—*Walking on the Level.*—On a truly horizontal surface, the most economical rate of progress is 4·5 *kilometres* (2·8 *miles*) *an hour*. This enables an unburdened man to cover 45 to 50 kilometres (28 to 31 miles) in the day, with 2 minutes' rest at every kilometre.

When the man is carrying a burden the *economical pace*, that which costs the organism least, is 4·2 kilometres (2·6

[1] Jules Amar, *Le rendement de la machine humaine*, Paris, 1909. (Doctor's Thesis ; out of print).

miles) an hour, the burden weighing from 20 to 22 kilogrammes (44 to 48·4 lbs.). But to realise the *maximum* daily performance, the weight of the load should be 45 *kilogrammes* (99 *lbs.*) and the rate of progress 4·8 *kilometres* (3 *miles) an hour,* while the day's work should consist of 7½ hours, with 2 minutes' rest every 600 metres (650 yards). An adult of 25 to 40 years of age can carry this load of 99 lbs. for an average distance of 26 *kilometres* (16 *miles) a day.* But if the pace is increased to 5·5 kilometres (3·4 miles) an hour, the distance will be reduced by almost one half, no matter how the intervals of rest may be arranged. Multiplying the distance in metres by the weight in kilogrammes of the man and his load, and we shall obtain a figure of not more than *three million metre-kilogrammes* as the daily output, the average being two and a half million metre-kilogrammes. Experiment gives ½ calorie as the equivalent of 1,000 metre-kilogrammes.

It should be noted that in the carrying of pigs of cast iron, each weighing 42 kilogrammes (92·4 lbs.), Taylor, in 1912, obtained similar results, his figure being two and a half million metre-kilogrammes. The rate of progress and intervals of rest, however, do not altogether agree with our results, and his methods are different. But this only makes the result more interesting. As for the foot-soldier, it is best to give him a total burden of 30 kilogrammes (66 lbs.), while his normal pace should not exceed 5 kilometres (3·1 miles) an hour.

In connection with the subject of troops on the march, this is a fitting moment to speak of a practice of which somewhat erroneous views are held : I mean the practice of resting the men by making them *mark time* for a few minutes. Now marking time expends energy ; it costs a third as much, sometimes half as much, as marching. We have measured this expenditure of energy, and find that it increases in proportion to the *rhythm* of the steps and the *height* to which the feet are raised. Marking time should therefore be moderated in respect of the two constituent factors, in order that it may be reduced to a mere species of massage, which takes the stiffness out of one's legs.

LVI.—2. *Carrying Burdens Upstairs.*—In carrying burdens upstairs the conditions of the maximum output are : The weight of the burden should be 40 kilogrammes (88 lbs.). The pace should be 430 metres (1,370 ft.) per hour. The day's work should be limited to 7 hours, 2 minutes' rest being taken on each journey of 8 metres (26 ft.) measured vertically.

The expenditure of energy is then represented by 8 calories per 1,000 kilogramme-metres (1 calorie per 893 foot-pounds), the unit here called a kilogramme-metre [1] being equivalent, in the energetical meaning of the word, to 16 times the conventional unit described as the *metre-kilogramme.* In other words, we expend the same effort in covering 16 metres on the level as in lifting ourselves through a height of 1 metre in the same time.

When we *descend* a staircase the contraction of the muscles is less than on ascending ; it is employed principally in *restraining* our tendency to fall, and the more rapid the descent the less energy is expended. We may estimate the saving of energy effected by the muscles as 50 per cent., so that we expend barely 4 calories per 1,000 kilogramme-metres of descent.

LVII.—3. *Walking on an Inclined Plane.*—The problem of walking on sloping ground requires special investigation, which demands a costly experimental equipment. I will confine myself here to giving a few results which I was able to obtain by chance means (Fig. 50), and to which the recent contributions of the Carnegie laboratories have added scarcely anything. [2]

The slope of my inclined plane varied from 8 to 13 centimetres in the metre ; that is, the gradient was from 8 to 13 in the 100. Let us call this inclination *i* (in centimetres).

[1] The kilogramme-metre is, of course, the metrical unit of work ; it is the work performed in lifting 1 kilogramme to a height of 1 metre, or in exerting an effort of 1 kilogramme along a path 1 metre in length.

[2] Benedict and Murschhauser, *Energy transformations during Horizontal Walking,* publ. No. 231, Washington, 1915.

The distance covered on the slope, L, is deduced from the distance covered on the level by the following ratios :

Ascending : $L' = \dfrac{L}{1 + 16i}$

On descending : $L = \dfrac{L}{1 + 10i}$

These ratios are approximate, but are quite sufficiently exact in practice.

LVIII.—4. *Cycling (Professional)*.—From a very large number of experiments carried out by means of our *ergometric*
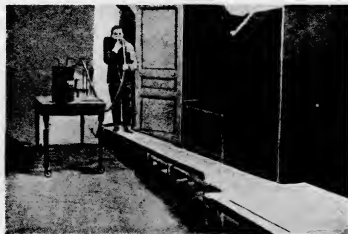

FIG. 50.—Study of Walking upon an Inclined Plane.

cycle, we determined the fact that the *normal* rate of pedalling is 45 to 46 revolutions per minute. This corresponds with an *economical pace* of 16 kilometres (9·94 miles) an hour, which does not overtax the rider. According to Leo Zuntz, the equivalent of 1,000 metre-kilogrammes is 0·27 calories, which is half the equivalent of the work done in walking the same distance.

The bicycle should always be adapted to the stature of the cyclist, as regards the height of the saddle and the length of the crank. Attention must be paid to the attitude of the

body, in order to reduce its oscillations, and to diminish the stooping of the bust.

The distance to be covered daily will be determined after examining the physiological condition of the rider, who in any case, but above all if he is addicted to racing, must abstain from the employment of alcoholic drinks.

When the bicycle is loaded, or when a cycle pushes a vehicle in front of it, as in the case of tradesmen's delivery cycles, the speed will be diminished in proportion to the load. Supposing that the driving wheel and the wheels which carry the load are of the same diameter, then if the load to be carried is represented by P, the speed will be :

$$v = \frac{35}{\sqrt{P}}$$

v being expressed in kilometres per hour and P in kilogrammes. This formula is deduced from a consideration of the moving forces of the motor and the thing moved. In any case the load should not be so great that v is lower than 5 kilometres (3·1 miles) per hour.

LIX.—5. *Agricultural Labour.*—The agriculturist will henceforth be obliged, to a very great extent, to practise the mechanical cultivation of the soil, making use of small motors. We shall see that these will be of considerable utility to discharged and wounded soldiers. But we will briefly give a few figures relating to the *best output* of agricultural workers.

Digging or shovelling requires the employment of a spade or shovel weighing 1·7 kgs. (3¾ lbs.). Loaded, it should not weigh more than 10·25 kgs. (20·55 lbs.) at most. The effort of thrusting the shovel into the earth should average 15 kgs. (33 lbs.).

The wheelbarrow should bear a load of 100 kgs. (220 lbs.), exerting a pressure of 20 kgs. (44 lbs.) on the handles, while the resistance offered to propulsion will be only 4 kgs. (8·8 lbs.). The employment of a two-wheeled barrow is advantageous.

From the agricultural point of view properly so-called, every crop and every field constitutes a problem of varying factors ; the nature of the soil ; the nature and quantities

of manure ; the amount of water used for watering purposes ; its head or pressure ; the tilling of the soil ; the germination of the seeds ; the number of plants per unit of surface ; mowing and reaping ; fighting against parasites and stormy weather ; the propitious seasons for each of these operations ; and the perfecting of the implements employed ; all questions which we could not touch upon here without diverging from our programme.

For the rest, we must refer the reader to Book VI. of *Le Moteur Humain*.

LX.—B. Physical Training and Functional Re-Education.

—To our thinking, the aim of the physiological organisation of labour is essentially utilitarian. Sports, athletic perform-ances, etc., do not greatly interest us ; a robust, well-trained workman is of infinitely greater value than the most famous athlete ; while horse-racing, that sport so beloved by the people, will never make for the progress of the equine race. The war, I imagine, has opened the eyes of all in this respect.

However, as an efficacious hygiene, and a bodily discipline, *physical training* possesses one very potent virtue, from which we must not fail to profit. It teaches us to control our attitudes, and adjust our movements, and it trains our muscles ; that is, it gives human energy full play and develops it to the utmost.

It is applicable (but not exclusively) to normal subjects, improving them physically and raising their physical standard ; and it may also be extended to persons of weakly constitu-tion, and to those who are physically backward, or are suffering from physiological want ; above all, it may be applied to the *functional re-education* of the infirm, who are to-day so numerous. I shall not deal separately with education and re-education ; their object is the same ; their methods are the same, and their province is the same. Both are guided by the same scientific principles.

LXI.—I. The Principles of Physical Training.—The

principles of physical training are those of *a muscular activity*

varying its effort and its pace by insensible degrees, to be deter-mined by the general condition of the organism.

This effort will be *constant*, for we find a constancy of effort under the ordinary circumstances of life, and physical train-ing should *never* call upon the *total* efforts of the individual, subsequently to diminish them. Numerous appliances for the administrations of *mechanotherapy* wrongly apply this law of decreasing effort, which is known as *Schwann's* law. This law, formulated by Schwann in 1837, states that " the *absolute* effort of contraction which remains available in a shortened muscle diminishes in proportion as the contraction increases." Let us note that Chauveau's law expresses the same fact in an inverse, but completer formula : " The force developed by a muscle increases with its degree of contraction, or shortening, and with the resistance which has to be over-come." It follows that *muscular force* regulates itself in accordance with the resistance encountered ; it does not waste itself in vain ; it may increase to large proportions without involving a shortening of the muscles, just as it may do so by means of this shortening alone. Thus it makes use of *isometric* and *isotonic* contractions[1] only to exert very great force. This is not the case in normal activity, and such are not by any means the circumstances adapted to the physio-logical training of the muscles. Whatever the nature of the movement, the object of the effort made will be to overcome a constant resistance, which it will be useful to increase day by day if it is desired to carry out a process of training ; but to vary it in the course of a single exercise, and to subject the tension of the muscles to sudden variations and absolute shocks, which wrench the fibres and lacerate the nervous filaments, is the very negation of any scientific method of functional education.

If we abandon the idea of demanding their maximum of effort from the muscles, a course which would risk overtaxing them and cause them to atrophy, there is nothing to justify the principle of variable resistance, or even of decreasing

[1] *Isometric*, without shortening, but with increased tension ; *isotonic*, with shortening but with constant tension of the muscles.

resistance. Exercises are of physiological value, and are useful, only if the forces called into play are *sub-maximal* and *continuous*. In this case they produce their full effect upon the locomotive system, giving suppleness to the joints and developing the power of the muscles. Just as they cause, when pushed to excess, *contracture* and an elastic fatigue of the tendons, so their harmonious employment provokes irritability of the nervous, muscular, and tendinous fibres, stimulating their elasticity and increasing their strength, and induces an increased respiratory and circulatory activity, which profoundly influences the phenomena of nutrition. From this results what is known as *functional hypertrophy*. We see the mass of the muscles increase, not by the addition of new fibres, but by the increasing diameter of the old ones, which become thickened, storing up reserves of nitrogenous materials.[1]

Physical training and functional re-education, therefore, produce a total effect, a massive action, on definite groups of muscles. They perform a work of synthesis, of *synergetic training.*

The analysis of the movements is necessary in quite special and temporary instances ; but eventually we find ourselves thrown back upon *synergy*, as it is demanded by nature, in conformity with the most reliable teaching of theory and practice.[2]

LXII. Factors of Physical Training.—The State of the Organism—Alimentation—The Seasons.—However, physical training does not consist merely of the regulation of muscular action. The spirit of the geometrician is not sufficient. Attention must be paid to the *condition of the organs*, to the power of the heart and the muscular system, to the elasticity of the respiratory cycle, and to the *age* of the subject. The *child* is naturally impelled to squander his energies ; education, while allowing this activity to develope, will impose upon it the necessary discipline, which will preserve him from over-

[1] Morpurgo, *Arch. ital. Biol.*, Vol. XXIX., p. 65, 1898.

[2] Concerning functional and manual re-education, see the present writer's article in the *Journal de Physiologie*, pp. 821-871, 1915.

exertion and bodily malformation ; so that it is important that we should possess clear and sufficient ideas of human physiology. The youth is exposed rather to the risk of over-taxing his brain, in the strenuous endeavour to pass examinations, to obtain degrees or other qualifications, which will fit him for his chosen career and reward him with the joys of success. He should be induced to rest from activities of this nature by devoting himself to moderate physical exercise, in games or gymnastics, which, provided all excess be avoided, will restore the balance of his energies.

Up to about the forty-fifth year games or sports, provided they are not of a violent nature, constitute a potent factor of neuro-muscular training, and increase the resistance of the organism. As one advances in years the function of the muscles surrenders its pre-eminence to the function of the brain ; the man increases, so to speak, in dignity ; he is more occupied with the things of the mind ; he is more of a man. " All our dignity resides in thought," said Pascal with justice.

Physical education would miss its aim if it disregarded the human understanding. Whenever it prescribes exercises calculated to refresh the brain-worker, it will select them from among the simplest and the most automatic. Otherwise the man would be burning the candle at both ends. To the *old man*, whose movements have lost their vigour and celerity, whose cardio-vascular organs are less resistant and less elastic, moderate efforts and a deliberate pace are suited ; for example, those of walking. Entertainments and amusements, provided they do not evoke violent emotions, are for him reconstituents of the nerve-centres. We must get this idea well fixed in our minds, that life rapidly increases in intensity; then its intensity remains constant ; and then, during a long final period, it diminishes little by little. The curve of energy terminates in a gentle slope (Fig. 51). And as this period corresponds with a moderate and fastidious function of nutrition, so must the expenditure of active energy be limited to the strictly necessary ; otherwise the organism will be in no condition to make up for any extravagant expenditure.

We see how far physical training is governed by the principles of physiology, and why without these it would go astray. They are its *raison d'être ;* without them it could not have been devised. From all antiquity indeed, it has been known that the activity of the muscles maintained the body in health, and games were born of this utilitarian idea. Cyrus, king of the Persians, forbade the eating of a meal before the body was fatigued by some kind of exercise. Lycurgus founded baths and gymnasiums, and, effecting a cruel elimination of weakly subjects, became, after his fashion,
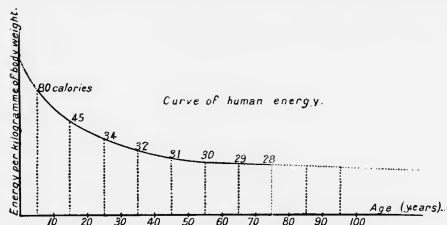
Fig. 51.—Energy produced during the Day of 24 Hours at various Periods of Life.

the ancestor of the Eugenists. The Greeks and Romans were wonderful organisers of athletic sports. Hippocrates and Galen expatiated on the subject of sports and games, often exhibiting a sound judgement. Even in the depths of Asia they were the preoccupation of the ruling classes. In the year 23 B.C. wrestling was regarded as a most noble sport in the empire of the Mikados. From gymnastics the next step was to " medicinal gymnastics " or hygiene.

Hygiene, therefore, is the basis of physical training. Hygiene should render sports and games wholesome and enjoyable, should regulate them, and determine their intensity and their duration, and should adapt them to the age and constitution of the player.

It should also take into account the law of *functional hegemony,* by virtue of which the maximum of life repairs to the active organs, to the detriment of the rest. It follows that the good hygienist will forbid the performance of heavy work immediately after a meal, that is to say, in the midst of the digestive process ; nor will he approve of the performance of intense intellectual labour following upon a condition of muscular fatigue.

The character of the alimentation absorbed, as we have already stated, is in itself a factor of training (see §XL). Between the commencement of any sort of work, and the end of a meal, an interval of half an hour [1] should be observed when the diet is rich in carbohydrates.

LXIII. Functional Re-education. General Laws.—As for the infirmities, differing in aspect and in gravity, which usually affect the locomotive organs, they are the province of *functional re-education* properly so called.

The persons whom we subject to the process of functional re-education are passing through that rather ill-defined phase which precedes complete recovery : the so-called period of *consolidation.* During this phase the cellular vitality is in full swing ; the tissues are undergoing regeneration, and increasing their powers of resistance, while the functions are becoming re-established. However, this anatomical and physiological restoration is subject to the effects, from the dynamical point of view, of *malformations, adhesions, displacements, ankylosed joints,* and *atrophy of the organs.* Vicious consolidations are not rare, often originating in faulty methods of immobilising fractured limbs, and sometimes to the exercises prescribed by an *irrational mechanotherapy.* The real object of functional re-education consists in re-establishing, or at least in improving, the *motor condition* of the man, the exercises

[1] A mixed or albuminous diet necessitates an interval of twice or three times this length. Thus starchy foods and saccharine foods favour protracted exertion ; they assure the energy of the system of an economy of about 5 per cent., and constitute a safeguard against organic disturbances. The values of exercise and of rations depend very considerably on the season. The reader will remember that we have already dealt with this point (Climate, § XLVII).

being regulated by the *form of his movements*, and the *average power* of the muscles which produce them ; lastly, in stimulating the tissue-repairing processes.

Natural movements may be referred to three types :

Movements of translation, in which the member is displaced *without rotation,* remaining parallel to itself. Such movements are produced when the member is actuating a jointing- or smoothing-plane, a saw, or a file, and in various gymnastic exercises :

Movements of rotation, in which certain points remain fixed, constituting the horizontal or vertical axis upon which the rotation is effected. This rotation is generally partial, limited by the play of a hinge, like the movement of a gate swinging on its pivots ; it may also be a simple oscillation :

Helicoidal or *screwing movements* combine the two foregoing movements ; they combine translation with rotation. Such are produced when the hand is working a screw-driver, or when the whole upper limb is turning a large key. It is worthy of remark that the screwing movements developing from left to right are more frequent than the reverse movements. Hence the origin of right-handed screws, corkscrews, etc This must be connected with the fact that right-handed persons are in the majority, and that the right-handed screwing movement is an economical movement for the right arm, as is the left-handed screwing movement for the left arm.

All forms of movement are referable to the three preceding types ; it is enough to reproduce these latter *in the planes in which they normally occur,* with the force and amplitude which characterise them in the healthy subject, in order to be sure that we are giving the muscular system that real *physiological training* outside which there would be nothing but danger and empiricism. Whether in the case of wholly normal persons, or in that of the infirm, this training will always be graduated as regards effort, speed, and total duration. It will not be forgotten that the contraction of the muscles produces **a** movement which is necessarily alternating and oscillatory, in place of a continuous rotation, and which allows time for

the accomplishment of the process of intra-cellular repair. The life of movement therefore assumes the aspect of a *periodical series of actions and intervals of repose.*

LXIV. **Force and Amplitude.**—The force and amplitude of the movements of the limbs must therefore be determined in the case of the person to be re-educated, and compared with those of the normal subject. In practice we compare the wounded limb with the whole limb. I may add that the same remarks apply to the various segments of the limbs, and to the stumps of amputated limbs.

But it may happen that a joint has grown *stiff.* Then the nearest joint—in the case of the knee-joint, for example, the hip-joint—takes its place. The conditions of movement, of walking, are changed, and favour a fresh mode of muscular synergy. It is necessary, therefore, to seek mechanical appliances which may prevent the atrophy of the quadriceps, and impose small movements on the ankylosed bones, so long as their fibrous and tendinous covering retains a certain amount of elasticity, or provided that radiography has not revealed an irremediable osseous adhesion.

All the movements of *locomotion* will be treated in this way, with the alternative objects of re-establishing the normal function in the atrophied limb, or of contending, by means of re-education, against a more or less complicated infirmity, in order that mere stiffness may not develop into ankylosis, while atrophy is at least kept in check. Only definite cases of ankylosis or atrophy will obtain compensation from the *articular or muscular substitution* of the adjacent segment of the limb, stimulated by actual training exercises. It is only during this process of reinforcement that a rational and economical substitution may be established, guided by the instinct of the least effort or the minimum of constraint. The *adhesions* to which the wound has given rise gradually relax, allowing the movements of the articular surfaces a greater amplitude ; the elasticity of the ligaments increases, and the bones become polished by renewed friction, destroying the asperities which remain after the consolidation of the fractures.

It will not be forgotten that the contraction of a muscle may modify the contraction of muscles at some distance ; for example, the strength of the flexor muscles of the fingers is diminished if the articulation of the wrist is the seat of a rigidity which keeps it flexed, or of a nervous degeneration which relaxes the extensors.

No attempt must ever be made to re-educate an articulation still capable of suppurating, or a limb painful to the touch or imperfectly consolidated, *and the process of physical training must never be carried out hastily.*

There is no method of classifying those cases which can profit by functional re-education ; there can be none, for the diversity of the wounds received—in respect of their gravity, their localisation, and the age of the wounded man—is incalculable. What we can classify are the movements which have been compromised by the wound, and their importance in the locomotive cycle, in the active life of the persons treated. A special class will be that of those who have suffered *amputation*, in whom we shall develop the strength of the muscles of the stump and the mobility of the principal articulation. This preoccupation is justified by the necessities arising from the wearing of a *prothetic appliance*, on the arm or leg, which is often too heavy for the stump. We shall take the opportunity of returning to this subject when dealing with the *work of war-cripples* and *prothesis.*

LXV.—II. **The Technique of Physical Training and Re-education.**—Physical training, and re-education of a functional character, in order to succeed in the directions which we have just defined, will have little need to borrow from the often disastrous technical methods of *mechanotherapy* and *physical culture.* It must substitute a rational method for the empiricism of the old methods.

As we explained, it is necessary to train the activities of the *upper* and *lower* limbs in a gradual manner, avoiding any overtaxing of the nerves or muscles. The organism will reveal the effects of this gradual training by a synergy of effort. This result will be obtained by means of the *ergo-*

metric cycle and the *cheirograph*, of which we have already made mention, and the *dynamographic bulb.* It will be verified by means of the *arthrodynamometer.* We will describe the details and the use of these instruments.

(1).   *The Ergometric Cycle.*—The ergometric cycle consists of a flywheel W, weighing about 36 kilogrammes, which forms the hind wheel of a bicycle, of which only the frame and the pedals have been retained ; the whole is adapted for men of medium stature, but the height of the saddle may be adjusted if need be. The rim of the wheel is grooved, and in the groove lies a
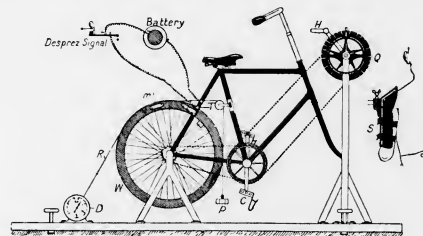

FIG. 52.—Diagram of ergometric Cycle.

ribbon of steel, R, which forms the brake ; one end of it supports a plate P, on which weights may be placed, while the other end is attached to a traction dynamometer, D, provided with a dial, which may be made self-registering (Fig. 52).

When the rider works the pedals the ribbon causes an amount of friction, F, which corresponds with the pull marked on the dial. The virtual distance covered by the flywheel is multiplied by the force required to overcome this friction, F, which gives the amount of work performed by the legs. Each revolution of the pedals corresponds to a peripheral distance of 6 metres, or to three turns of the flywheel, the latter having a circumference of about 2 metres. Under these conditions the

bust is completely at rest, so that the legs alone are working against a resistance which can be adjusted at will by altering the load on the brake, and at a pace which the subject will choose to please himself ; the mass of the flywheel will prevent sudden variations of speed.

On the other hand, the crank-wheel C transmits its movement to a similar wheel which is fitted with a crank-handle, H, so that by actuating this latter the arms will perform work, which may be measured as before. The highest position of this handle extends the arm in a horizontal plane in the case of a subject of average stature. The subject may seat himself before the crank, on an adjustable stool, at a convenient height ; if he stands the movement of the arm will bring into play the articulations of the wrist, the elbow, and the shoulder, just as the movements of the rider utilised the articulation of the hip, the knee, and the ankle.

Moreover, by moving sufficiently out of the vertical plane of the crank, he will make a greater demand upon the muscles of the shoulder and a portion of the trunk, while the effort of the elbow will be reduced, and *vice versa*.

In this comparatively brief explanation I cannot discuss the conditions of the gradual advance of the process of physiological training, as effected by means of the ergometric cycle. I will content myself with remarking that for adults the following brake loads will be employed, in increasing order : 300, 500, 700, 1,000, 1,200, 1,500, 2,000, 2,500 and 3,000 grammes.

Having noted by means of the chronometer the pace voluntarily adopted by the patient, this will be increased at the rate of 10 revolutions of the flywheel per minute every second day, the exercise lasting from 10 to 15 minutes. The pace will be set by a metronome, marking from 30 to 300 oscillations.

We may regard as satisfactory an activity which works against a brake load of 3 kilogrammes at a pace of 200 revolutions per minute, for a quarter of an hour without a halt.

At this stage it will be as well to estimate the expenditure of energy and note the degree of fatigue, in conformity with the indications already given.

LXVI.—The experimental equipment is completed, in the case of patients who have suffered amputation, by a metallic splint which is screwed into the place of the crank-handle, and which fulfils the same office, with the advantage that the

Fig. 53.—Re-education of Stumps.

stump can be strapped into it by means of straps surrounding the splint. This latter moves before a quadrant, Q, graduated from 0° to 180° on either side of the vertical ; it carries an indicating needle, which shows the amplitude of the articular

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movements, in adduction and abduction. In order that the
centre of the articulation of the shoulder shall lie precisely
on the axis of the brachial splint, the patient is seated on the
adjustable stool, whose height is regulated according to his
stature (Fig. 53). The muscles of the stump maintain its
oscillation, and one might assist it, at the outset, by gently
working the fly-wheel. A patient whose arm has been ampu-
tated, for example, will guide the movements of the stump by
working the pedals. The rhythm of the oscillations and the
resistance of the brake will be moderate ; they will depend
upon the useful length and the actual strength of the stump,
which will obviously be greater when the fore-arm only has
been amputated.

In patients who have suffered amputation of part of the
lower leg, the knee-joint being preserved, an experimental
prothetic appliance enables them to exercise the stump ;
the sound leg will sustain the effort strictly necessary to
re-educate it and call forth its activity in the most uniform
manner. But as a matter of fact the lower limb is best
re-educated by the use of a simple *wooden leg,* or by the
employment of a *splint.*

In these various cases we must supervise not only the
gradation of the exercises performed, but also their continuity,
advancing to the limits of physiological training.

Finally, on the rim of the fly-wheel is affixed an elastic
strip of metal, *m,* which, as it passes the fork, comes into
contact with a similar strip. The result is a ticking sound,
and the patient is required to make this coincide with the
ticking of the metronome. The time required to obtain this
coincidence will be measured by the chronometer ; this will
form a practical means of measuring the personal equation.
When this period does not exceed 15 seconds the subject is
quick ; his personal equation is small, and he is adapted to call-
ings demanding rapid movements. If it is longer than 25 seconds
he is a slow subject. A classification of subjects made in this man-
ner will constitute a guide to the manual re-education of wounded
men, and their re-establishment in the industrial system.

The fork of the cycle is fitted with two terminals, T, con-

nected with a battery, in whose circuit is a self-registering
Desprez signal. At each revolution of the wheel the circuit
is closed, and a notch is marked on the record-paper ; and
if the patient's progress is normal all these notches will be
made at equal intervals. Otherwise we must suspect either
a lack of co-ordination in his movements, or a slight tendinous
rigidity, or muscular retraction, with secondary lesions. The
cycle, with its accessories, constitutes the principal appliance
employed for the purposes of physical education.

LXVII.—(2). *The Cheirograph.*—I give this name to a type
of ergograph designed for the hand, with its whole gamut of
movements, including those of the wrist as well as those of the
fingers. Mosso's digital ergograph, of which this is a transforma-
tion and an improvement, serves merely to register the flexions
of the right middle finger. Its usefulness is therefore extremely
limited; moreover, it possesses several disadvantages, which we
have already described (in *Le Moteur Humain,* p. 391). The
cheirograph, on the contrary, possesses an excellent means of
attachment to the fore-arm, which leaves the entire hand free,
including the wrist, permitting of flexor, extensor, and abductor
movements, and also of lateral inclinations. The registering
apparatus consists of the ordinary form of Mosso's carriage,
constructed to work with the minimum of friction (see
Fig. 40).

Thanks to this apparatus, the hand, that delicate segment
of the upper limb, so well adapted to movements involving
skill and celerity, may be subjected to a functional education,
for whose results, as we have assured ourselves, we have not
very long to wait.

The appliance by means of which the cheirograph is affixed
to the fore-arm is mounted on a heavy frame. It may be
inclined to the right or the left, in order to support the right
or the left fore-arm. To this end it is provided with a pivot
and a clamping nut at one side (Cl, Fig. 54). The fore-arm
is firmly held and supported by the semi-bracelets, *b, b',*
which are suitably adjusted. The hand then rests upon a
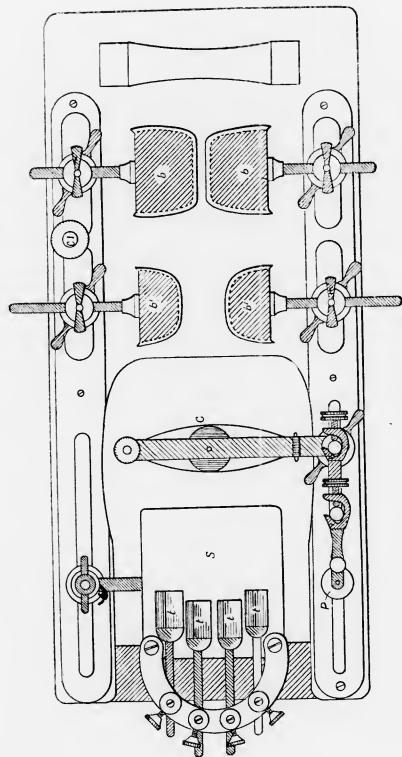fixed slab S, on which the fingers are fully extended.

FIG. 54.—The Cheirograph.

Above this is a semi-circular bar carrying four rods, terminating in the small metal thimbles, t, t; their position can be adjusted by means of clamping-screws with milled heads. Brought down upon the slab S these thimbles cover the phalanges and hold the fingers immovable. It is then possible to liberate this or that finger at will, and to perform work with it, the rest remaining motionless.

Moreover, the hand is pressed against the slab S by means of a clamp C, which presses upon the middle of the metacarpus. Lastly, at one side is a pulley device P, which transmits to the registering apparatus the movements of the thumb. The transmission is effected by means of a cord attached to a small leather ring clasping the second phalange, the other end of which is connected with the registering apparatus.

The slab and the set of thimbles, and also the pulley, can be swung aside, leaving an empty space in which the hand and the wrist can perform their movements of flexion, extension, and lateral deviation. In this case the cord is attached to a clamp similar to C, in which the hand is placed and then closed, the wrist of course remaining perfectly free.

All the movements possible are eventually converted into traction on a thread, which, at one end of the Mosso carriage, supports a weight which can be varied at the will of the operator. Registration is therefore always in the same direction, but the amplitude of the tracings varies. Care must be taken that the initial position is adjusted by means of the screw, as if the cord were allowed any play the different tracings could not usefully be compared.

If these precautions are taken, and if the weights to be lifted are suitable—from 200 to 1,500 grammes for the fingers, the voluntary rhythm observed by the patient being noted, and then increased to 60 contractions per minute—it will quickly be realised how salutary these exercises are. They should be continued from 3 to 10 minutes.

On the tracings thus obtained we can follow the increasing amplitude of the curves, which will record the degree of flexion and the mobility of the articulations. Records obtained with the same weight at regular intervals will give a faithful

account of the functional condition of the hand, and will permit of later comparison. Those forms of exertion which involve celerity of movement (as typewriting, stenography, fencing) are those which are particularly benefited by this method of training, which is also of great value in cases of articular rigidity.
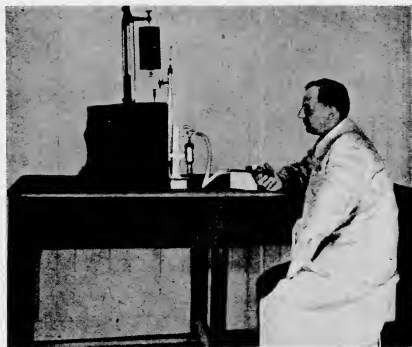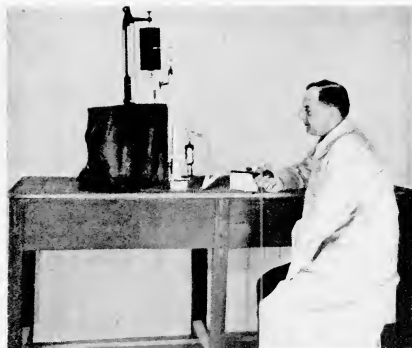

Fig. 55.—Bulb Dynamometer.

LXVIII.—(3). *The Dynamographic Bulb.*—With a view to continuing the training of the hand in respect of its total effort of compression or squeezing, we have employed a very simple piece of special apparatus : the *dynamographic bulb,* or *bulb dynamometer.*

This consists of a strongly-made pear-shaped bulb of india-rubber having a capacity of 125 cubic centimetres. This is filled with air at any desired pressure by means of a cycle pump. It is connected with a mercury manometer, one of whose arms is capacious enough to contain at least 500 cubic

centimetres of mercury, while the other branch, which is longer, contains about 30 cubic centimetres. This latter

Muscular Fatigue — Bulb Dynamometer

Pressure of 3000 grms.
(6·6 lbs.)

Pressure of 1750 grammes.
(3·85 lbs.)

Pressure of 500 grammes.
(1·1 lbs.)

Time in Seconds

Normal subject

Pressure of Hand on Bulb.

1   2

Before Fatigue   After Fatigue

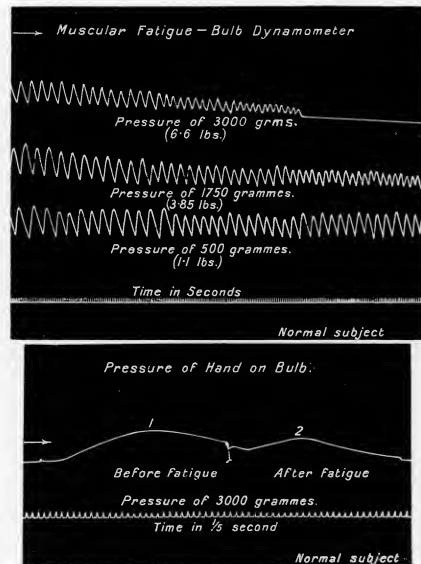Pressure of 3000 grammes

Time in ⅕ second

Normal subject

Fig. 56.

contains a registering float, so that all displacements of the mercury caused by the pressure of the fingers, above the known pressure of the air in the bulb, are recorded on a register-

account of the functional condition of the hand, and will permit of later comparison. Those forms of exertion which involve celerity of movement (as typewriting, stenography, fencing) are those which are particularly benefited by this method of training, which is also of great value in cases of articular rigidity.

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Fig. 56.

contains a registering float, so that all displacements of the mercury caused by the pressure of the fingers, above the known pressure of the air in the bulb, are recorded on a register-

ing cylinder (Fig. 55). The oscillations of the mercury are damped by a constriction in the tube connecting the two arms.

The difference of level in the two arms measures the total pressure. We have marked, on a graduated vertical stem, the values in grammes per millimetre of displacement (difference of level).

The compression of the fingers causes a variation of the initial pressure, and the variations furnish a tracing which is graduated once for all. The muscles may be trained until from exerting a pressure of 100 grammes they exert one of 5 kilogrammes, which is a very high figure. A hundred contractions cause the hand to perspire, while massaging the entire fibro-muscular system. It is possible to follow the advance of functional fatigue as the hand continues its exertions and also the rhythm of the movements (Fig. 56).

LXIX.—(4). The *Arthrodynamometer.*—As the process of training advances, the strength of the muscles and the amplitude of their movement increases. These two factors, which yield an exact measure of the results, are determined by means of the *arthrodynamometer.*

This instrument measures the *angular displacements of the limbs or segments of limbs, and the absolute forces exerted by the groups of muscles which control them, whatever degree of flexion may be in question.*[1]

It consists (Fig. 57) of two parallel strips of steel jointed like a pair of compasses, and turning easily upon this joint. It measures all practically useful degrees of flexion, that is, from 30° to 180°. The method of using the instrument will, as we shall see, explain its instruction and adjustment.

Measurement of the Angular Movements of the Limbs.—The arthrodynamometer is applied to two segments of the limb, on either side of the articulation, and in a determined plane, It is provided with semi-bracelets and armlets of thin steel, to which very strong straps are affixed. These are tightly fastened, in order that the legs of the instrument may be

[1] See *C.R. Acad. Sc.,* 7 June, 1915, Vol. CLX., p. 730.

firmly attached to the segments of the limb, and incapable of slipping (Fig. 58).
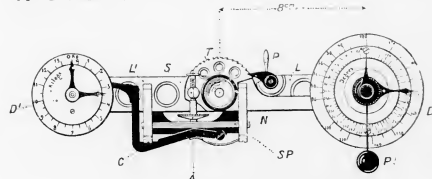

FIG. 57.—Elevation of Arthrodynamometer.

In order to make an angular measurement, the central nut N of the pivotal joint is unscrewed, and the pawl P, of which the tip engages in the toothed wheel T, is raised. Then the adjusting screw A, which is seen above the leaves of the spring SP, is turned until it is brought into contact with the swivel S. If the wearer now flexes one segment of a limb upon the adjacent segment (the foot upon the lower leg, the hand upon the fore-arm), the leg L of the compasses actuates a pulley lying beneath the dial D, thereby causing

FIG. 58.
Manner of adjusting the Arthrodynamometer.

the small pointer to rotate, when the angle of flexion may be

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Fig. 58.
Manner of adjusting the Arthrodynamometer.

read on one of the circumferential scales of the dial. In the same way the lateral movements of the hand and foot may be measured.

For Movements of the Entire Limb, whether in a frontal or sagittal plane, the instrument is adjusted by clamping the nut N and immobilising the joint. The angle of displacement is then given by the position assumed by the swinging pointer or plumb needle PL, a pointer with a counterweight which plays the part of a plumb-line. It indicates the deviation of the limb from the vertical in either direction.

The amplitude of the movements in any given plane is thus correctly determined. It is compared with that required in athletic exercises or games, or in the management of machinery or the handling of tools.

Measuring the absolute strength of the muscles.—As for the force exerted by the muscles, we may determine its absolute or maximum value at any degree of flexion. In this case the nut N is loosened, and the pawl P lowered upon the toothed wheel, while the adjusting screw A is turned until it touches the leaves of the spring. This firmly engages the pawl in the interval between two teeth, and suppresses all play when the muscular effort is made.

The effort exerted upon the leg of the compasses is therefore transmitted to the toothed wheel, and thence to the leaves of the spring, against which the adjusting screw A is pressed. The deformation of this spring, though barely perceptible, is amplified by the bent lever or crank C, which terminates in a segmental rack, which actuates a pinion whose axle carries the dynamometrical pointer moving upon the dial, D′, on which the values are read.

Graduation of the Dials.—On the dial showing the angles of flexion the degrees are marked from 180° to 30°; on that showing the displacements of the entire limb they run from 0° to 360°; but it is as well to define the direction of the angular deviation by the words *lateral* (to right or left) or *sagittal* (to front or back) in order to avoid misunderstanding. More detailed explanations are necessary in respect of the measurement of absolute force. The muscles, acting upon

the mobile segment of the limb, while the spring opposes its flexion, actuate one arm of a lever with a *variable moment.*[1] The force exerted by them, even if it were constant, would produce an effect upon the dynamometer which would increase in proportion as the movement itself increased with reference to the axis, as it does, in proportion to the flexion, and up to a certain limit. Now the absolute effort of the muscles is not constant; it tends to exhaust itself during the shortening of the muscle (Schwann's law). It is therefore difficult to determine it exactly, in the living subject, at every stage of this contraction.

For this reason we have adopted a *conventional* graduation; the force is supposed to act normally at the extremity of the leg of the compasses, in the centre of the attachment, at a distance of 8 centimetres (3·2 inches) from the centre of the hinge. The length of this arm of the lever being known once for all, we have contented ourselves with reading the efforts in kilogrammes on the small dial, in place of the kilo-gramme-centimetres which express the movements. If the exact position of the muscular insertion on the movable bone be known, it will be possible to deduce the effective component of the effort, and to calculate the actual power of the muscles concerned.

This method of measurement enables us to follow the variation of the forces exerted during the movement, and to appreciate the results of the training process. It is essential whenever it is desired to undertake the scientific organisation of the work of re-education, whether functional or professional.

(5). Lastly, in order to restore the *movements of rotation* in the arm, I make use of an apparatus based on the principle of the cam, called a *gyrograph,* which applies both force and movement, and measures them.

LXX.—III. **Applications.**—*Attitudes of the Body.*—Physical education, conducted according to the technical principles explained above, will produce rapid and lasting results; it

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[1] The moment is the product of a force and the arm of the lever to which it is applied.

will easily lead the subject to the verge of the most active *athletic exercises*, for once the organic functions have been subjected to supervision and training there will no longer be any possibility of exhaustion or failure (see the whole of the chapter on *Fatigue*).

But *functional re-education*, which is applied more particularly to wounded soldiers, must be kept within moderate limits, progressing at a very gradual rate, under penalty of accidents.

Both physical education and functional re-education, in short, are based upon the fact that human activity should be *physiologically regulated*, and that it becomes, by that very fact, economical and hygienic.

Attitudes.—We may remark that even when lying down, or sitting, or standing, we do not all go about the business in the same fashion, as we are ignorant of the economical and hygienic attitudes. Measurements of the energy expended have plainly proved as much.

Complete repose of the body is obtained in the recumbent position, but by lying on the belly, not on the back,[1] preferably inclining to the right side ; the saving is 7 to 8 per cent. over the seated position. In the latter the body should be upright and symmetrical, the feet touching the ground without effort ; above all they should not hang clear of the ground.

In sitting down to read or write care should be taken that the fore-arms rest on the table, and that the shoulders are drawn back ; if the desk is too high it will involve an awkward and very fatiguing attitude, which will impede the movements of the hand in writing, while too low a desk necessitates stooping.

The *erect position* is still more interesting ; it concerns the working-man and the engineer alike ; it is of particular importance to the overseer ; it is the attitude of the soldier, the watchman, the policeman, the omnibus conductor, the railway-guard. It comprises two symmetrical attitudes and one asymmetrical pose, which are plainly shown in Fig. 59 (left to right).

[1] Liljstrand and Wollin, *Skand. Arch. f. Phys.*, Vol. XXX., p. 199, 1913.

The *normal attitude* (the *Normal-Stellung* of the Germans) is regular ; it places all the articulations in a single vertical plane ; but it is a source of fatigue. The *convenient attitude* (*Bequeme-Haltung*) is more stable, and contracts the muscles less. However, it does not reduce the expenditure of bodily energy to the minimum, as does the easy attitude, of which
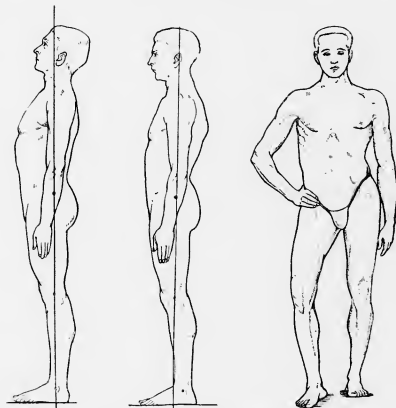
Fig. 59.—Erect Positions of the Body.

we all have an instinctive experience. Deportment calls for a convenient, symmetrical attitude, which eases the vertebral column, slightly hollows the loins, and expands the chest, retracting the abdomen and the shoulders. This undeniable condition of muscular tension causes some fatigue, but it has a very favourable influence over the whole economy ; it conserves the energies and maintains the stature.

M

Let us compare the cost of these various attitudes, counting the energy-expenditure of the recumbent man as 100. We shall obtain the following figures : [1]

Recumbent position (in pronation)		..	..	100
Seated position	..	..	..	..	107
Standing	Easy pose	..	..	..	110
	Convenient pose	..	..	..	113
	Normal pose	..	..	..	132

LXXI. Locomotion.—*Gymnastics.*—Locomotion, too, is capable of improvement. We have already indicated the economical factors of a walking gait. It must be added that *above* 170 *steps to the minute* it is more profitable to *run ;* which, for that matter, all those do whose lower limbs are short. Very frequent short steps cause the prompt appearance of fatigue ; I will venture, in this connection, to utter a legitimate criticism of narrow skirts for women. The subject is a less serious one than that of corsets, but none the less hygiene deserves a certain consideration ; and it is by no means the enemy of *fashion.*

Certain populations, such as the Arabs, effect a saving of 20 to 25 per cent. in their locomotion, and in the use of their legs in general. Their output is thus greatly superior to the average. Now these folk practise the so-called *flexed walk* (of which I have said what is necessary elsewhere), which aids progress and reduces the efforts of muscular contraction. This is, for that matter, the gait of the weary labourer, the navvy returning from his work, or the human beast of burden harnessed to a heavy hand-cart (Fig. 60) ; it diminishes the oscillations of the bodily centre of gravity, and increases a man's steadiness on his legs. Under ordinary circumstances the trainer will combine walking and running exercise in order to increase the rhythm of the heart and lungs to a fitting extent ; he will note these at the close of 20 or 30 minutes' training exercise. Once again, a progressive advance will be observed, which will exclude any danger of strain or over-exertion.

[1] See *Le Moteur Humain,* p. 444.

The principles of economy, finally, may be applied to many attitudes ; from that of the man who writes or draws or plays a musical instrument to those of the athlete, the sportsman, and the soldier.

Walking, running, jumping, climbing, crawling, and such modes of activity as *boxing* and *fencing,* are subject to the same laws of rhythm, measure, and physiological regulation. I

Fig. 60.—The Flexed Walk.

have said all that is needful on this subject in Book VI. of *Le Moteur Humain,* to which the reader may refer (p. 469).

Gymnastics, at a certain period of re-education, when the articulations have resumed their normal play, becomes a training method of great value. I am speaking above all of movements of the arms and legs. To these I add exercises with dumb-bells of 1 to 3 kilogrammes (2·2 to 6·6 lbs.) weight, terminating, under the most favourable conditions, with a weight of 5 kilogrammes (11 lbs.). The movements will be made in pronation, then in supination, at the rate of 80 to 100 per minute (Figs. 61 and 62), always vigorously, with the body in the normal attitude.
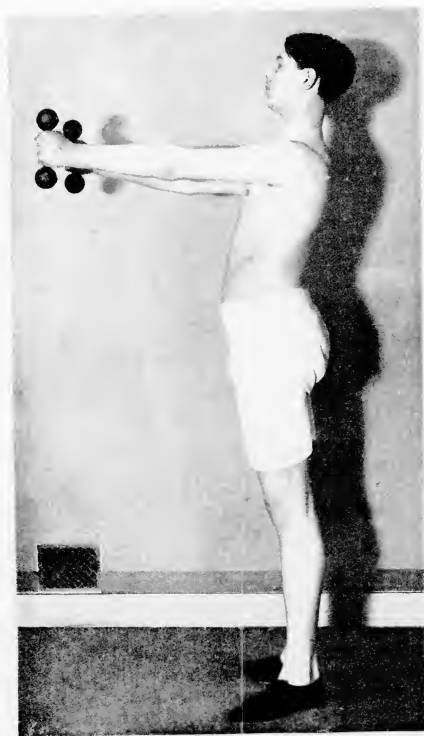
Fig. 61.—Gymnastic Exercises with Dumb-bells (Attitude of Body improving).

Other gymnastic and acrobatic exercises merely bring into harmony the movements of the centre of gravity and the force of the muscular contractions.

Dr Lachaud, of the Chamber of Deputies, insists upon

Fig. 62.—Gymnastic Exercises for increasing Strength.

simple gymnastic exercises, with weights, cords, and pulleys; he recommends what has improperly been called *manotherapy*. I cannot unreservedly support the views of this distinguished politician, for the movements practised should in the first place be *guided*, lest they should be performed incorrectly, and produce malformations, at an age when the soldier's skeleton is often not completely ossified, or the muscles fully developed.

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Gymnastic exercises are suitable for normal subjects, and these they develop harmoniously; applied to wounded soldiers and the infirm they are merely an auxiliary method; they cannot constitute a complete means of functional re-education. By combining the education of the movements with observations of fatigue we have completed the training of a few young men and of many hundreds of infirm subjects. To the numerous attestations which would seem out of place in a work of this nature I should prefer personal verifications. Any one may test for himself these simple, quick, and economical methods. Experience, aided by an enlightened judgement, will never employ them without success.

LXXII. **Summary—Physical Activity.**—The identity of the methods which should guide both physical education and the activity of the craftsman is obvious. It results from the geometrical and harmonious forms of the contractions of the muscles; it reveals itself indeed in the very effects of this contraction, since fatigue, in the last analysis, is always an intoxication.

Of the principles of the *art of labour*, I would lay especial stress upon order and the selection of movements. If, in order to execute any physical action whatever, we make the strictly necessary movements, which alone are *useful* in executing it; if we eliminate the useless movements, and regulate the *succession* of the useful, we shall effect a great saving both of time and fatigue. Our education too will profit greatly; a moral treasure will be added to the betterment of our well-being. The organisation which I am speaking of involves the art of making movements appropriate to an end, and of making a rigorous selection of the same, tending to an economy of effort; in other words, of ordering them and utilising them in the best possible manner.

Selection and *order* are, in truth, the characteristics of the new method, which will presently work an economic revolution to which no other can be compared. It is not purely mechanical; it does not turn a man into a soulless body, a blind and tireless force; it embraces all the data of physiology and

psychology, of which it alone is able to display the parallelism and the unfailing harmony. It would seem to have taken for its guide this saying of Montaigne's: " It is not a body, it is not a soul that we are forming; it is a man; we must not make two of him."

CHAPTER VII

THE ART OF LABOUR (continued)

INTELLECTUAL ACTIVITY [1]

LXXIII.—In the intellectual domain, which on every hand surrounds the domain of physical forces, and overflows it, we have attempted to introduce the discipline of the art of labour, that is, the same laws of selection and co-ordination, of the organisation of movement. The application to the things of the mind of the laws of general mechanics seems in itself to be a somewhat hazardous proceeding ; in any case it is anything but finally worked out. But being based upon facts which are perfectly established, although not large in number, and being moreover carefully verified and controlled, it is lacking neither in interest nor in social and, above all, *pedagogical* value. For these two reasons it is worthy of the reader's attention.

LXXIV. **Complexity of Intellectual Work.**—The problem to be solved does not necessarily presuppose the knowledge of that something which has in turn constituted the object of meditation of the philosophers, the theologians, and the physiologists—namely, the mind or soul ; or, in a narrower acceptation, the intelligence or understanding. The classic methodology indeed distinguishes between the intelligence of the will and that of the perceptions ; it places them in a hierarchy of the faculties, which are more and more highly spiritualised as they are further in the scale from perception.

[1] This chapter was published as an article in *La Revue*, for 1 June, 1914, under the title *L'Art de penser*. I should mention that since that date (in 1916) a volume has appeared under the same title, whose author, one Clément Goh, has plagiarised my article, and has most unhappily spun it out over 200 pages.

But from the experimental and physiological point of view the matter wears another aspect. Will and perception are, in unequal degrees, both functions of *nervous activity*, strictly adhering to its modalities ; they are its *qualitative* expression. The good or the evil we do, said Diderot, depends on the condition of our diaphragm. This determination, or considered as a doctrine, this *determinism*, does not influence the function of *thought ;* it perceives, with a kind of internal vision, that which is good and that which is bad, appreciating, comparing, and judging, apparently quite freely.

The intelligence is therefore the series of operations which effect the representation and the classification of our *ideas*. Because it resuscitates *images* and transfers them to its plane of vision, it fulfils a function of the *affective* order ; that is to say, subordinated to the condition of the nervous system ; it arouses great numbers of *neurones*, re-awakens the cellular vibrations, and harmonises them with the vibrations of other cells ; a circuit of vital energy unites the elements of the cerebral substance. This is a purely physiological process, due to several causes. Sometimes it is provoked by the peripheral sensitive neurones, those of the sight, the touch, the hearing ; sometimes by *humoral variations ;* a fit of indigestion, like an emotion, stirs up the whole swarm of *dreams*, and disperses them upon all the winds of fiction. To these solicitations the nerve-cell responds by a greater activity, and the reflexes draw upon the muscles of the face, with strokes of varying emphasis, the ripples of the tide of emotions which has swept through them (Fig. 63). These muscular contractions have all the diversity of the emotions themselves, and, by their force and duration, they reveal the gravity of the sensitive phenomenon ; sometimes there is a *contracture*, a painful spasm. This muscular effort causes the blood to surge into the organ of thought. Also, during prolonged or intense intellectual exertion, or during slumber agitated by dreams, the temperature of the brain undergoes a slight increase ; the pulse is very marked in the temples ; there is a feeling of heat and a smarting sensation in the face, but the peripheral organs are sacrificed ; the feet and legs are cold.

When such phenomena are frequently repeated, when the periods of mental activity are combined with too few periods of repose, there are manifestations of *cerebral fatigue;* the head grows heavy, the eyes become bloodshot; the sight is troubled by a diminished convergence of the pupils, and by a
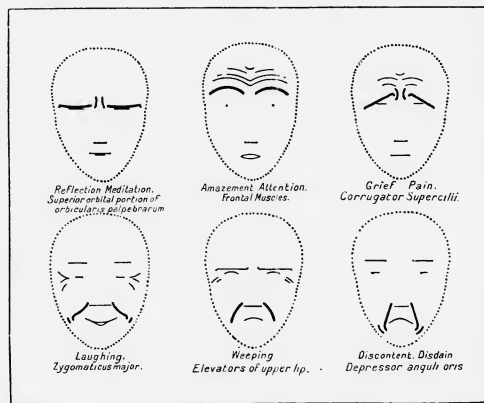

FIG. 63.—Diagrammatic Expression of the Emotions.

convexity of the lens; the respiration is superficial and irregular, and the heart slows down.

Toxic waste products accumulate in the organism. They are eliminated in the urine, but their effect upon the *power of the muscles* is already revealed by a rapid diminution of the tracings obtained by means of the cheirograph, while their effect upon the *sensibility* is betrayed by high readings on the aesthesiometer. The *respiratory exchanges* increase in intensity,

by about 7 to 11 per cent., and the consumption of oxygen measures the extent of this complex activity, which is increased by attention, but diminished by training and habit.[1] The digestive secretions, on the other hand, are modified, and partially inhibited.[2] The vegetative life diminishes its activities, in order to give full scope to the life of the higher nerve-centres. Then, as we have said, the *mental images are revived,* and the intelligence has performed a task of a physiological nature. Only the selection and the ordering of ideas appear in the intelligence as something of a different essence, a really transcendent power.

This is precisely what we wished to establish : namely, that the exercise of the mind mingles operations which are true nervous reactions, reflexes, affective conditions, with other important operations which dominate the sphere of perception. But we of course intend it to be understood that both categories of phenomena result from the physiological activity of the organism, and are subject to all the disturbances and eddies of life ; they levy tribute on the resources of the organism ; they represent organic effort ; they involve a certain expenditure of energy which produces *fatigue,* for nothing in nature is gratuitous.

And here we are at the very heart of the problem stated in the beginning : whether, in the living world as in the inanimate world, energies are not merely transformed ; if, for example, muscular energy has its source in the chemical energy of the aliments absorbed, to what origin are we to refer intellectual energy ? Whence does it spring ? And how can it be utilised without loss ?

LXXV. **The Origin of Intellectual Energy.** — Two American scientists, Benedict and Carpenter, after laborious experiment, succeeded in demonstrating that *the exercise of thought by itself occasions very little expenditure;* it figures as a very small item in the alimentary budget. A man who

[1] Johanssohn, *Skand. Arch.,* Vol. XVIII., p. 85, 1898;—Becker and Olsen, *ibid.,* Vol. XXXI., p. 81, 1914;—*Die Umschau,* No. 19, 1912.

[2] Brunacci and De Sanctis, *Archivia di Fisiol.,* Vol., XII., p. 441, 1914.

expends 2,400 calories in the twenty-four hours for his
energetical maintenance expends barely 9 or 10 calories
more when he devotes himself to long meditations, resolves
difficult equations, makes learned calculations, and in short
thinks, for 8 hours a day.

The subject was enclosed in the calometric chamber already
described (Fig. 3), where he was presented with a heavy German
treatise on mathematical physics. The energy radiated in
the form of heat was measured outside, unknown to him.

On the other hand, I have verified the fact that the consump-
tion of oxygen is only *very slightly* modified when students, in a
condition of perfect repose, devote themselves to complicated
mental operations.[1] It is obvious that in these different cases
we are estimating the *increased expenditure of intellectual
energy*, seeing that the mind is never absolutely at rest.   But to
represent me as saying that the expenditure of energy rises,
at the moment when the mind begins to work, from zero to a
positive value, and to find in my argument a positive contradic-
tion in terms, as did a writer in a Dutch review, is, as anyone
will perceive, completely unjust.[2]

" The great difficulty," we repeat, with Voltaire, " is there-
fore to understand how any creature comes to have thoughts."

And indeed the whole difficulty is there. For him who
considers the nervous operations which record images, pre-
serve them, and repeat them, it is easy to conceive that they
never cease ; that they are an attribute of life, and its accom-
paniment. No state of rest absolutely interrupts them,
serving as a starting-point from which we can measure the
expenditure of energy which their profound and invisible
exercise involves. In this respect the principle of the con-
servation of energy which governs the universe remains
unshaken. But the mind retains its mysterious secret ; it
remains withdrawn, beyond the cycle of the vital energies ;
a fact which is wholly disconcerting, unless indeed we have
recourse to a recent explanation, inspired by the phe-
nomena described as *radioactive*. Certain substances undergo

[1] I have described these experiments in *Le Moteur Humain*, p. 278.
[2] *Wettenschappelijke Bladen*, Vol. IV., p. 1, 1912.

disintegration, *spontaneously* dissociating themselves, with
a secular deliberation, producing light, heat, and electricity.
The example of *radium* points to this transformation of
matter, which exhausts itself and disappears when once it
has liberated all its reserves of energy.

Can it be that thought also constitutes a radioactive pheno-
menon ?   Is it evolved from the disappearing cerebral sub-
stance by a process as yet inexplicable ?

If this were so the differences between the radioactive or
dissociative powers of the cerebral substance would explain
the differences of intellectual vigour and vivacity to be
observed in different persons, just as the characteristic qualities
of the sources of light affect its intensity or illuminating power.
However, the radioactive origin of thought is not proven.
Although it has been noted that the nervous tissues, and
especially the brain, are highly radioactive,[1] it has also been
recognised that this property results from the absorption of
the traces of radioactive substances contained in our solid
and liquid aliments, and in all mineral waters.

All that we can venture to suggest is that the disaggregation
of the cells of the brain liberates intellectual energy directly
and exclusively, without the usual intermediaries : without
heat or the emission of electricity. For our cells are assuredly
the theatre of a material evolution which affects even the
molecule, breaks it up into infinitesimal fragments, and in
particular destroys its *phosphated elements* and *nuclei*. These
are the compounds rich in phosphorus, the colourable portion
of the nerve-cell—that is, the *chromatin*—which, being by
reason of their organic bases in an unstable molecular condition,
seem doomed to this slow destruction, and exhaust them-
selves in the operations of the cerebral cortex, the very body
of the cell becoming reduced.[2] And as in the activity of the
muscles, the organic development taking place in these nuclear
substances produces *toxins*, and renders *acid* the chemical
environment which, normally, and in a state of repose, is

[1] A. Caan, *Sitzungsb. d. Heid. d. Akad. d. Wissensch.*, V., 1911.
[2] Lugaro, *Arch. ital. Biol.*, Vol. XXIV., p. 258, 1895 ;—Guerrini, *ibid.*, Vol.
XXXII., p. 62, 1899 ;—Marinesco, *Engelm. Arch. f. Physiologie*, p. 89, 1899.

alkaline. It is an actual disaggregation, which is aggravated by external stimulations, such as luminous impressions,[1] but above all by fatigue. Then the nervous reactions grow weaker and thought is arrested, inhibited, poisoned ; it has even been noted that the filaments of the neurones shrink and retract themselves, so that the multiple connections thereby effected within the brain are less to be relied upon.[2]

Rest, sleep, food, that is to say, above all, the *blood,* will repair this temporary derangement.

We must wait for more precise details as to the delicate and wonderful process which gradually exhausts the nervous substance, giving rise to an energy of the highest order ; in the meantime let us consider *the work peculiar to the mind.* And let us proclaim that it is possible to organise this work, to employ it more effectually, if we resort to rational methods, and to effect considerable savings. For under the infinite variety of its forms it necessitates operations of the same nature as those of physical activity, and as far as the economy of effort is concerned there is nothing to distinguish between the exercise of the mental functions and the exercise of the muscles.

LXXVI. The Organisation of Intellectual Work.—But the work of the intellect is *twofold.* On the one hand it consists of finding, within itself, or seeking for, *ideas.* On the other hand, it sets itself to *organise* these ideas ; and by this we mean to utilise these ideas in an *order* and according to a *plan* which increases their value.

It seems that the first undertaking, being comparatively easy, has less need than the second of being improved and reinforced. The reserves of ideas which a man possesses in his own brain are enriched by reading, conversation, and daily experience. Now this, too, demands a certain discipline. To read, or to be read to, would serve no essentially useful end did not the attention apply itself to the task of extracting new

[1] Muller and Ott, *Pflüg Arch.,* Vol. CIII., p. 493, 1904 ;—Lodato and Miceli, *Arch. d. oftalm.,* Vol. X., pp. 294 and 327, 1903.

[2] *Trans. Lab. Inst. Solvay,* Brussels, Vols. I. and II., 1897-1898.

ideas and furnishing the mind with them ; if it did not defend the mind, by a process of rational elimination, against all the incidental reflections and literary stop-gaps which in general inflate speech without enriching it.

It behoves the mind, which is endowed with the power of selection, to exercise it rigorously, while expending upon it as little energy as possible.

The *child* should be educated according to these principles ; he should be taught to take hold only of those ideas which pre-eminently concern a subject, instead of running after all those that glitter, and whose brilliance often masks their fragility. The schoolmaster or lecturer should show him how the art of speaking, of speaking well, serves to give a striking prominence to those mental conceptions which are worthy of it, and to keep them forcibly in view. I should never place my academic trust in a professor who was a bad speaker, and who, far from exhibiting, as in a show-case, the pearls of knowledge, buried them in the trash of his obscure verbiage. Moreover, eloquence is genuine only when it is *ordered.* The best orators possess perfectly organised brains, which they have not necessarily overloaded. Erudition, of a widely miscellaneous character, would be almost a hindrance to them, while by moving along the same grooves of thought it enables them to discuss their subjects readily, and as though without effort, training and adapting them to a specialised mode of intellectual activity.

We would not have this specialisation exclude a solid *general culture;* on the contrary, it should find, in such a culture, its natural setting, the setting which will best harmonise with it. But the division of labour, which limits the mental field, is far less to be feared than the lack of mental order caused by excessive work undertaken in many directions. One cannot lose one's way in an alley, but the forest is treacherous.

Writing, like speech, demands order and method, so that the reader may easily assimilate the *dominant ideas,* the only ideas which count, and so that his attention may not be divided. The art of writing consists, therefore, in being

simple, direct, and accurate, that is to say, *clear*, and in conceiving ideas clearly in order that they may be clearly expressed. After all, the writer is always understood if his knowledge is profound and methodical. He can, in the words of Montaigne, teach Greek and Latin "without tears," and more particularly can he teach the sciences, whose essential object is the *economy of thought* by means of demonstrations and general laws. How much time and effort could students of all ages be saved if they were not only too often compelled to re-read an author several times before understanding him! But how many writers could be dispensed with if the reign of darkness in our teaching centres were to terminate! In our days people would not tolerate a police force which should forbid the circulation of confused writings, which should forbid the vagabondage of ideas along the paths of literature. Nevertheless, it is a question which deserves consideration. A man does not write for himself; he addresses himself to readers young and old, and professes to *instruct* them. The problem is to make sure that this instruction is elaborated in such a way as to cost the recipient the minimum of effort, and to afford him the pleasure and advantage of shaping his consciousness.

The facts which teach are the important facts, because they hold the attention and are representative; they are true *symbols*. Science employs such symbols in order to spare us detail; it seeks out numerical relations, and then, retaining only the general character of these relations, it ignores the figures. Algebra, in this respect, effects an intellectual economy by means of its notations; the same is true of physics, and every science which has a mathematical character.

The *logical character* of the relation between facts should be established with equal care. For example, consider the tie of *causality*. It is good that one thing should involve another as its consequence. What a wonderful discovery is this of the universal and logical connection of the conquests of knowledge!

The most beautiful laws cover the widest domain. Such are Newton's law of *universal gravitation*, and Descartes' law of

refraction. And they are the most admirable because they lessen the fatigue of the intellect.

Lastly, other ideas take shape from the experience of life, lived in all its fulness, life as it is, with all its vicissitudes, like a sea that abounds with reefs. Never drag the growing youth wholly out of reach of these difficulties of life; from those which are the work of men even less than from those which originate in things. The egoism and the moral defects which are to be encountered in our fellow men will teach him. But one must take care that he extricates himself from his mistakes, and fights his social battles, by upright and honest conduct. Virtue and truth are terrible weapons which triumph over all things. One must learn to handle these weapons, and to do so one must serve an apprenticeship of action.

This is how the task of the mind should be maintained and regulated, considering it from the point of view of its regular alimentation and repair. No useless aliments; none of bad quality; no waste of cerebral energy.

LXXVII.—The second point of view, we noted, embraces the *work of the mind* which utilises accumulated materials. It proceeds as follows: Do we wish to reflect on a given subject, or to solve a scientific or philosophical problem? Gradually our ideas awaken, bestir themselves, and hasten forward. Generally they make their appearance in the natural order; that is to say, singly, without connecting links, each determined by a sort of reaction or reflex.

The natural order may be compared to that of a battalion on the march when the step is broken. The men march "all anyhow," diversely impelled, given over to hazard. To one who sees them from a distance the battalion is marching as a whole, despite the confusion of ranks. But it travels less quickly; it presents less cohesion and solidity, and a less smart appearance than a battalion which is keeping step, closing its ranks behind its leaders, and obeying their orders.

The same discipline ought to be applied to the ideas which travel in a host through the whole region of the mind. At

first, when we are still apprentices, we allow them to follow one another *spontaneously* at the point of the pen, and when not one is left worth the trouble of recording it in writing, we subject them to a severe examination. That idea will come first which in the natural order was third or fourth, and so with the rest. All will be classified, set in a hierarchy, so that the accessory shall not get the better of the principal idea ; so that an internally controlled order of succession shall preserve both their intrinsic value, and that secondary value, which results from the logical relation established between them.

Such a concatenation excludes prolixity and digressions and useless references. The economy of words is the saving of time by means which signally increase the force of the argument, and unfold it in a concentrated light.

It is the function of *practice*, steadily maintained, to impose upon the mind this manner of working, whatever the basis of ideas upon which it is building. Habit finally renders easy, almost automatic, the classification of ideas, provided that the *attention* corrects at every moment the deviations from this discipline. One can understand that this very discipline finds it difficult to accommodate itself to the many keen excitations which, from without, shake its ranks, and why *reflection* and *meditation* are more efficacious when one is able to abstract oneself from one's surroundings. A richly furnished brain will elaborate coherent and ordered ideas in this " ivory tower." A scientific man, a director or manager of factories, or an engineer, will be able more usefully and with greater certainty to collate the items of his acquired experience. We should never follow the " first impulse " ; it is the most heedless impulse ; it is a reflex determined by an external action ; in spite of the popular saying, " first thoughts " are not " best thoughts." Let us examine ourselves ; let us take time to hold debate with ourselves. Let us accustom our *cerebral channels of inhibition* and our *neurones of control* to the necessary task of elimination. The man who, to some extent by heredity, and largely by education, possesses this type of nervous organisation, should under

any circumstances hold an advantage over other men ; for he will display *firmness*, *judgement*, and *method*. He will be understood, and obeyed, without effort.

We may be equally certain that one of the most important preoccupations of the *orator* is to cause the various elements of his speech to be grasped without fatigue, and in perfect order. If his *memory* is not very reliable he has recourse to a plan drafted in advance. The *ornaments* of speech which he employs are intended to capture the attention, to prepare it to follow his argument, and to sustain it to the end. They encourage his auditors to accept the intellectual labour demanded of them, and they break its continuity. For the activity of the mind is *rhythmical* and *intermittent*, like the activity of the muscles. The psychical ego withdraws itself at intervals from the strain of thought, taking refuge, by preference, on some flower-strewn bank.

It would seem that *rhetoric* is born of this twofold need of order and method. Rhetoric, then, we must have ; but not too much of it. It would be contrary to the scientific principles expounded in these pages to reduce the domain of ideas in favour of the domain of words, even were these the most gorgeous, the most happily chosen. The adornment of speech is a means, not an end. When I run through several pages of a book which is stuffed with fine phrases, and am unable to discover in them even a few fine ideas, I quickly put it aside.

Happy is the writer who can make his reader think ! He will never have a foolish reader.

LXXVIII. **Applications.**—In nature movement is *squandered*, because those conditions do not exist which favour its perfect utilisation, either in the physical order or the intellectual. Mechanical science endeavours to achieve this perfection in inanimate motors and living motors alike ; but it will be a long time before it succeeds, despite the great progress effected in the last few years.

As far as thought is concerned, mechanical science can do little more than furnish indications and simple practical rules,

which enable us to reduce fatigue, and to give a true direction to the activity of the mind. This activity, as we have remarked, " is susceptible of discipline and method. Great intellectual power may manifest itself in disorder and uncontrolled overflow. Such waste is the result of an unscientific education and unruly habits of thought. The delicate mechanisms of the brain must neither be exhausted nor forced to go awry." [1]

We should therefore reason out our actions, and we should sort out our ideas, arranging them clearly, while clothing them, if we will, in the fashions of the day. Otherwise we run the risk of refutation, or incomprehension. In rehearsing them we must give all our attention to the matter, weighing every word, considering each purpose. If the work is of secondary importance, and if, as a matter of professional necessity, it *must be rapidly executed*, it is expedient to sacrifice to haste a little of the intellectual labour which we should otherwise put into the work, unless indeed it is possible to reconcile haste and intellectual effort. The *mental effort* is measured by the attention, and *rapidity of thought* by the number of different facts embraced in a given time. Cerebral fatigue is the result of these two factors.

To diminish this fatigue, intellectual labour will be divided into periods of one or two hours, according to its nature, and these will alternate with periods of comparative repose ; that is to say, these intervals of time will be devoted to moderate physical exercise : to walking, games, or conversation.

A mental effort of several hours' duration enfeebles the cellular reactions, intoxicates the neurones, and thereby impairs the quality as well as the order of the ideas ; the writer hesitates ; the workman miscalculates ; both have suffered a temporary depreciation ; care must be taken that it does not become aggravated.

To devote two hours' attendance in class or lecture-room to the exact sciences, without a few minutes' interruption, is to commit an error in pedagogics ; for after the first hour the capacity to attend and the ability to understand are already

[1] *Le Moteur Humain*, p. 590.

diminished ; [1] more so in the afternoon than in the morning. But the fund of nervous energy may be reconstituted by a suitable diet and a little open-air *exercise*, by cheerful and amusing entertainments, by the distraction of the senses of sight and hearing. The monotony of work, whatever its nature, must be broken, in conformity with the *law of rhythm* which governs the organism, and which is inscribed in particular upon the nerve-centres of the brain. Obedience to this law alone will enable human activity to remain intact, regular, and efficacious.

This is why we should profit by these wholesome doctrines ; why we should endeavour to adapt the efforts of the mind to the result to be obtained ; to co-ordinate them ; to allow nothing to be dissipated in sheer wastefulness. As this discipline is more closely followed, a gradual diminution of fatigue is observed, though the nature of the mental effort and its duration remain the same.

LXXIX.—Such are the novel principles which I wished to expound ; it is not difficult to perceive their manifold applications, whether social or industrial. There is one application, however, which bears upon the intellectual development of the child ; it is the *art of teaching*, a subject which M. Marcel Prevost has vigorously treated in a few masterly pages.[2] This eminent writer reveals the full educative value of the scientific organisation of teaching, and the profound truths which underlie this organisation. Neither Taylor nor myself, who had considered the problem in all its general bearings, and had formulated laws which are in a sense universal, could so usefully have grappled with a special subject such as the art of teaching. And while we find a pupil of Taylor's condemning, even to excess, the use of *caligraphic ornaments ;* [3] while business men and administrative officials are, seemingly at least, expressing a certain desire for progress in the direction of a reduced production of superfluous documents, I like to recall this very curious passage of Montaigne's. "The letters

[1] Bellei, *Riv. sp. freniat. e med. leg.*, Vol. XXX., p. 17, 1904.
[2] See *Annales politiques et littéraires*, 21 December, 1913, to 29 March, 1914.
[3] Gilbreth, *Motion Study*, p. 100.

of this age consist more of margins and prefaces than of matter. How much rather would I compose two letters than close and fold one, who always resign this duty to some other, just as when the matter is finished I would gladly leave to another the duty of adding to it those long harangues, tenders, and requests, for which we find room at the close, and wish that some new custom should discharge us from it."

APPRENTICESHIP

LXXX. **Apprenticeship and Re-apprenticeship.**—Apprenticeship is the decisive factor of national wealth. It consists in the technical and psycho-physiological *shaping* of the man. Every profession necessitates an apprenticeship through which it becomes a habitude of the mind and the body, a habitude which to a varying extent leaves its traces on the organism and creates inclinations or aptitudes.

Without resulting in a kind of instinct, like the instinct of the bees to construct a comb, such hereditary tendencies make for perfection, for professional skill. The *repetition of the same actions, or the same trains of thought,* endows the nervous system with a peculiar sensibility, which facilitates the performance of these actions, directing and guiding the thoughts in a given path. We are familiar with many examples of this *professional vocation,* whether of musicians, or men of letters, or physicians, or soldiers ; and in the bygone centuries the professional vocation was a very great power in the heart of the *guilds* or *corporations,* and exerted sovereign rule over the family. During the last forty or fifty years all this has been completely changed, to the detriment of our prosperity. We have ceased to love the calling for its own sake ; our young men are proud and ambitious. " Ouvrier ne suis, apprenti ne daigne, fonctionnaire suis." (Workman I am not ; I do not deign to be an apprentice ; I am an official.) Men seek for situations which demand the least effort, yet reward them with wealth and honour. When we perceive how ignorance and incompetence rule throughout society we feel discouraged, and we understand why so many far-seeing persons blame

the *apprenticeship crisis*. For all, whatever the social plane on which they live, have need of apprenticeship; that is, of the lessons taught by things; of the lessons of life, so fertile in virtues, in ideas, and in the principles of discipline and education.

The age at which these lessons yield the best fruit is, as we have seen (§ 19), between 13 and 20 years for boys, and for girls between 11 and 18 years. *From the purely industrial point of view* the army of labour, in countries which have adopted conscription, should have completed its apprenticeship at the moment when it is called to the colours. In this way it is educated and instructed during the period of its physiological and moral growth. But to-day the wounded soldiers who are forced by the war to change their calling, the soldiers who are suffering from serious infirmities, and those who have suffered amputation, are entering upon a fresh apprenticeship, at the age of 25 and often of 30 years. This *re-apprenticeship* is obviously facilitated by the general experience and mental maturity of these men; it is none the less a very ticklish system of education, in which we must beware of committing blunders as to the *vocational direction* to be followed, and the *physical capacities available*. We shall return to this point later on.

The organisation of apprenticeship, therefore, confronts us with a twofold problem : a problem at once *technical* and *physiological ;* a problem of industrial practice and social hygiene.

LXXXI. The Present Condition of Apprenticeship.—But what, to begin with, is the *crisis* of which we hear people speak ? What was its origin, and what remedies have been found for it ? People complain that the environment in which the apprentice was formed no longer exists, precisely because the professional guilds and corporations no longer have any legal existence (in France owing to the Chapelier Act, 17 June, 1791), so that the atmosphere of industry, the service as journeyman, and the permanent guidance and advice necessary to the pupil, are things of the past. The Constituent Assembly

is said to have destroyed for ever the genuine school of technical education.

Again, the inevitable increase of the use of *machinery and mechanical methods* is blamed, for in the factory or workshop which works at high pressure the artisans, labourers, and apprentices are employed each upon an *elementary* task which forms part of a general task ; they are the wheels of a mechanical system in which the functions are not to any extent interchangeable. In this way the worker is familiar with *only a fragment of a trade,* a single element of labour. It is impossible for him to grasp his calling as a whole ; left to himself, apart from the factory, he soon realises his profound ignorance ; a worker in a watch-making factory, he does not know how to make a watch ; a shoemaker, he is incapable of making a slipper. This defect is real ; it is inherent in any organisation founded upon the *division of labour ;* it is therefore unavoidable.

Finally, it is said that the relations between apprentices and employers, and their rights and duties, are ill defined, in the absence of well devised laws and adequate means of arbitration. " Properly understood," writes Beignet, " the interest of both resides in the *rapprochement* of the two social entities, the working classes and the employing classes, by means of professional organisations." [1] But this solves nothing, and arbitration or agreement, which are always useful, do not modify the conditions of apprenticeship.

In France, the law passed on the 22 February, 1851, relating to the contract of apprenticeship, or indenture, has certainly accomplished a good deal in this connection ; it compels the master to teach the apprentice *the whole of his trade*, and not to employ him upon tasks which do not profit him in the matter of instruction, nor upon those which are beyond his physical strength, or injurious to health (Article 8). " A decision of the tribunal of Limoges, dated the 30 January, 1906, basing itself upon the Act of 1851 and Articles 1134 and 1137 of the Civil Code, ratifies the right of the parents to break a contract and obtain damages for the time lost if an employer

[1] A. Beinet, *La Décadence de l'apprentissage en France*, p. 18 ; Angers, 1911.

employs an apprentice only upon a portion of the work of his profession, which in no way adds to his personal education. 'Here,' declares Dubief, 'is a serious guarantee, a really efficacious protection.'" [1]

The law of 1851 is nevertheless insufficient; although it attacks possible abuses, it does not build up a system of controlled education; it does not aim at the improved education of the apprentice, and it does not adduce any element of decision as to the revival of trade organisations, and the defence of the *complete craft* against its subdivision by machinery. To legislate is not to organise.

LXXXII. **Technical Schools.**—A masterpiece of organisation and a means of serious control was the creation of trade schools, whose essential object is to educate and instruct, to form the mind and train the hand, to teach all the elements, theoretical and practical, of the trade or craft. "While it is true," said Millerand, "that in a few weeks a labourer can learn to operate a machine, it is no less true, and profoundly true, that the interest of national production, as of the producer himself, and the interest of the country, which has need of an educated and intelligent race, imperiously demands workers who are familiar with the whole of their calling; who possess sufficient scientific knowledge to understand the working of a machine, to repair it, and at need to invent improvements." (Quoted by Dubief : *loc. cit.*, p. 41.)

There were already schools of apprenticeship in France, even before the Revolution; even in the sixteenth century; there was the *Maison de l'abbé Étienne de Barberé*, founded in 1640, in the Faubourg Saint-Antoine; and the *Maison de Trinité*, still older, in the district of Saint-Denis, in whose favour a royal edict of 1531 authorised employers to take two apprentices in place of one, as was the rule.

These establishments recruited orphans more particularly; they were workshops in which labour, charity, and religion were mingled in curious proportions. Ecclesiastics managed them; employers or master craftsmen, who had withdrawn

[1] F. Dubief, *L' Apprentissage et l'enseignement technique*, p. 15, Paris, 1910.

themselves to this pious environment, provided the instruction. They competed, with the free employers and in the

FIG. 64.—The Stocking Trade (18th century).
To the left, a Stocking Maker. To the right, a Woman working the Lyons Spinning-Jenny.

shops, for the favours of the king and the protection of the police.

FIG. 65.—Workshop of a Norman Pin-maker (18th century).
The Workers are seated before glass Screens, which safeguard the Eyes from Dust and Filings.

And in spite of this precarious situation apprentices were trained in these workshops who made "shirts of mail and

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brigantines, which are conveyed to foreign countries ; weavers who make the old style of gold and silk laces, and others who make cloths of gold and silk (Fig. 64) ; makers of pins and needles (Fig. 65) ; purse-makers, makers of cards or combs for carding ; and other trades practised in France." [1]

But they did little work in these establishments, in order that they might the oftener sing psalms.

The intention was none the less laudable ; and I recall this attempt in order to show that the training of the apprentice should be purely professional.   If these charitable establishments had some excuse for giving precedence to religious exercises, the corporations of those days, and the employers, committed an abuse in making the pupil a domestic servant. " The apprentice was in fact the chattel of the employer," says Dubief.

The schools, on the other hand, give the apprentice liberty, but a *methodical liberty.* The Ministry of Commerce has inbreathed into them the spirit of the University ; not, as Bourrey justly feared,[2] in order to confound the methods of one governmental department with those of another, nor to allow one public office to encroach upon another, but, beyond all doubt, the better to foster technical education ; to rekindle it and light its path with all the fires of human knowledge. The choice of teachers is a guarantee against abuses ; it is for them to apportion the general instruction, without which all special instruction remains obscure and limited ; it is for them to proportion and harmonise, to select and adapt. Such should be the spirit of the curricula of these schools.

At the present time there are in France 80 primary professional schools,[3] of which fifteen are in the city of Paris. Private schools and State schools together, they undertake the instruction of 25,000 pupils ; they are assisted by the

[1] M. Fosseyeux, *Les Maisons d'apprentissage sous l'ancien régime,* Paris, 1913.
[2] G. Bourrey, *Le Problème de l'apprentissage et l'enseignement technique,* Paris, 1913.
[3] I take these figures from M. Barbe, *La question de l'apprentissage (Ligue française de l'enseignement),* Paris, 1913.

Société philotechnique de Paris (7,568 pupils), the *Société d'Enseignement professionel du Rhône,* at Lyons (5,632 pupils), and the *Cours industriels et commerciaux du Nord,* the offspring of the admirable efforts of M. Labbé (4,730 pupils), so that 125,000 young people are receiving the sort of education which is of use to them, costing the budget (in 1907) 7 million francs (£280,000), or 56 francs (£2 5s.) per pupil. However, there remain more than 800,000 possible pupils, not yet 18 years of age, who can find no place in these centres of thought and action. The partisans of trade schools accordingly declare that one must persevere in the effort and consent to an increased budgetary expenditure. But what is the character of the method for which so great an expansion is desired ? We have, according to M. Barbe, " the introduction of the workshop into the school, the intimate union of theory and practice, and their collaboration by means of the workshop and the business office, with the object of rendering our pupils immediately serviceable, on leaving, in the factory or the warehouse " (*Loc. cit.,* p. 16).

This collaboration is not effected in the same fashion in all countries. In Germany, where there are more than 700,000 pupils, each of whom costs 50 francs, the apprentice schools, the *Fortbildungs-Schulen* (for instance, the School of Mechanical Construction at Hagen, in Prussia, with 240 pupils), are organised in such a way as to complete the work of the factory ; but the latter must come first, and, so to speak, must form the young worker. The trade guilds have a real existence, and the wholly practical apprenticeship which they give is necessary in order that the worker may obtain the authorisation to practise his craft ; and, before this, (in order that he may attend the classes at the school. The training of the body takes precedence of the training of the mind ; and economic needs take precedence of intellectual needs. The German brain is a wheel in the German industrial system, driven by that system in the direction and at the speed which it finds convenient. The schools are created for the factories, and they increase their numbers and their specialities according to the local needs.[1] The classes are graduated and selected

[1] Curt Kohlman, *Fabrikschulen,* p. 65-72, Berlin, 1911.

with a view to producing intelligences of a certain given orientation, but practical instruction always comes before any other, and takes up more of the apprentices' time. The love of the useful is officially stimulated throughout Germany.

The two contrary examples of France and Germany are characteristic of the complex of ideas which in other countries have been applied with numerous variations ; the French methods have been applied most frequently, and the trade school of the French type assures the pupil *in the first place* of a general technical education, without losing touch with practice, or even with external factories and workshops.

To sum up, the present condition of apprenticeship is this : on the one hand the Government is endeavouring to create an organisation, if one may call it such, of which it has hardly determined the plan ; the industrial world, on the other hand, is animated by the desire for agreement and action, now following the light of economic science, now halting on the threshold of social reform. Desires and intentions are here, generous or exacerbated, but they are dreams which vanish in the daylight of reality. Apprenticeship requires a scientific method : principles, that is, which leave nothing to hazard, and which are sufficient in themselves. This we shall endeavour briefly to explain in detail.

LXXXIII. **The Organisation of the Apprentice System.** —The organisation of apprenticeship is a task which must be undertaken by and in the trade school. A natural prolongation of the primary school, it receives the child under the conditions most favourable for teaching him a trade. By the age of 13 there will have been time to teach him the elements of his own language, mathematics, and the physical and natural sciences. This indispensable knowledge cannot have created in him a vocation of any kind. He is therefore fully prepared to receive a special course of instruction, a theoretical and practical training, devised with a view to his chosen trade.

I would say that a *theoretical training is necessary ;* it facilitates apprenticeship, by explaining it ; it sheds its light over all the details of work, revealing its defects and qualities,

without which progress would be slow, and the finishing touches difficult or impossible ; above all, it develops the spirit of invention, a love of fine workmanship, and a deep-seated love of the craft or profession. Its imprint upon the mind of the worker is indelible ; and the worker, no less than the scientist, rejoices to perceive that experience responds exactly to the predictions of theory, and that genuine art is governed by geometry.

In modern society the future is to the best educated ; no one, I trust, would now repeat the heresy of Voltaire, " that only one pen is needed for two or three hundred hands." Pens such as Voltaire's, assuredly ; but the pens of the workers must be innumerable. And when the lessons of science are conceived in such a fashion that they give the apprentice a reasoned knowledge of his calling, extend his horizon, and refine his intelligence, it would be folly to dispute their prime utility. There is no example of a workman having regretted these lessons, and there are many examples to the contrary. Taylor, from being a mere porter, became an engineer by dint of educating himself, by paying excellent teachers. I would wager that he would rather have lost his immense fortune than his theoretical knowledge.

The lessons which the child has conned on his bench at school are engraved in his memory, and guide him all his life ; he will return to them, will consult his notes or text-books, to correct his judgement and guide his actions, for he has tested this teaching, has practised it, and has confidence in it. How many of us return, at times, to the reading of old lessons, piously preserved, and rejoice that the yellow paper still speaks the incomparable language of our masters !

From the primary school to the trade school there must be continuity along the paths of specialisation and gradation. The nature of the trade determines the choice of subjects to be taught, and the proportions to be observed among these subjects ; the apprentice who is to become a watchmaker or an instrument-maker requires a better knowledge of drawing, more exact science, more mensuration ; the French École de Cluses provides an admirable example of this mode of instruction.

But it will be realised that more natural science, more agricultural science, and more chemistry—and all adapted to the local needs—will be required in the schools which prepare the future tillers of the soil—that soil which, owing to mistaken ideas, is only too often deserted by our workers. It is not my object to say more of this here ; I leave it to the qualified teachers to tackle the prejudiced, and to inculcate another love of the fields and harvests than that expressed in the *Georgics*.

It has been said that the technical school produces theorists ; that it arrests the impulse of the individual mind. This is a ridiculous claim. Those who slander it would fain be theorists themselves ; knowledge did not come to them so young, and in a spirit of jealousy and vexation they protest against " royal roads." " Toil as we did : you must look for everything to the long and painful experience of life," they seem to say to these apprentices of fourteen years. These reproaches usually proceed from the working-classes. But I know workers who think differently. And how many seek, during the evening, to acquire a few rudiments of theory, despite the fatigue of the day ! These afford a sufficient reply to the others, and there is no appeal against their verdict.

As for the individual consciousness and initiative, they are imperfectly developed at the age of which we are speaking ; but after the age of leaving school they will develop normally, in a lucid and uniform manner ; life will very soon complete their development. I have already explained that we are brought up against a physiological and psychological impossibility if we seek to transform the period during which the human mind *absorbs* into a period of *restitution* and *creation ;* it is even imprudent to seek to hasten the latter too far, as Ostwald has many times warned us. For nature evolves by slow transitions ; if her movements are hurried a loss of vital force results, which is a more serious affair in the living organism than in a machine.

I claim, moreover, that the trade school has a twofold superiority over the workshop, whose defenders are still numerous ; I mean, of course, over the workshop alone. Its scientific superiority is obvious. The workman, while

he believes that he is teaching the apprentice the whole of his craft, is himself making no progress. From worker to worker the chain is prolonged and closed, and not the smallest link of science is added to it. It is a vicious circle. The horizon is confined to established facts, while without the skies are flooded with light. The teachers, on the contrary, grow more learned from generation to generation ; they play their part continually in the progress of the world, and their pupils profit thereby. Modern industry demands this constant development of the education given to the workers.

And there is, moreover, a *moral superiority* to be obtained by training the apprentice in the schools, which is all the more appreciable in that we are dealing with children, on whom bad examples, and unconsidered words and actions, exert a more pernicious influence. In this respect I cannot do better than quote the remarks made by Liébaut, more than thirty years ago, in a report read before the *Chambre syndicale des mécaniciens :* " Everyone is familiar," he said, " with the dismal fruits of apprenticeship in the workshop ; from the educational point of view it too often produces idleness, and an unreflecting and almost always unjust hatred of the employer, the foreman, and everyone who gives orders and has the right to expect obedience, together with disastrous habits of drunkenness and debauchery ; from the professional and educational point of view the apprenticeship is entirely lacking in method, and is accomplished only in a spirit of servile imitation and routine."

LXXXIV. The Technique of Apprenticeship.—In order that the school may give this professional instruction *as a whole,* the advantages of theoretical education and the environment which it affords the apprentice are not sufficient ; it must assure him of the practical training and instruction which is offered by the workshop itself.

The practice of a trade or craft is incontestably an art, but art is always the expression of a methodical, disciplined effort ; that is, of a science which has its own laws. The arts and crafts are applied sciences, whose eternal beauties, in bygone

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ages, enchanted the imagination to such a point that it erected them into Olympian divinities. The worker who possesses an absolute grasp of his craft is the equal of the scholar.

The principles which should guide the practical apprenticeship are of a *physiological* and *mechanical* order. In the first place, the teacher will carefully examine the aptitudes of his pupil; he will not leave him to mope at the lathe if he will only be happy when handling the plough; he will see that weakly subjects do not adopt callings requiring violent exertion; all the factors, in a word, which we have already defined will be considered, in order that the future workers shall be well equipped when they begin to practise their callings. Here the intervention of the teacher will be of the greatest use; he will advise the pupil's parents, and place his information before the director of the technical school. This information should be entered in the pupil's school report-book; it will help to illuminate the perceptions of parents and teachers. But I have already explained how far these indications should receive attention, and what restrictions should always be applied to them. Nevertheless, they are of very great importance.

The apprentices will be taught what *hygienic precautions* they should take to safeguard their health, according to the nature of their work, and what accidents are to be guarded against. They will therefore be on their guard.

They will be provided with elementary manuals of a nature to stimulate their love of their craft, to make them take a pride in it, to realise its nobility. The traditions of the guilds and unions must be replaced by the fruitful ambition to become model workers, learned in their craft, following and even hastening the march of progress. In creating this state of mind we shall have solved the whole psychological problem of apprenticeship, which so happily completes the physiological problem.

LXXXV. **The Education of the Movements.**—But we must resort to the graphic method, in its innumerable applications, as I have explained it by the example of the apprentice

Fig. 66.
Apprentice (Fitter) filing Metal. To the left, the Correct Attitude; to the right, the Incorrect. (The Sequence of the Pictures is from Top to Bottom.)

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using the file (LIII), for the experimental lessons which will instruct and discipline the young worker, and will fulfil, better than speech or writing, the office of correcting the beginner's faults, correcting his mistakes, and securing his attention. Dynamographic tracings, which can easily be obtained with a little ingenuity, should constantly be exhibited to the pupils, so that they may judge for themselves of their irregularity, in the case of a beginner, or their regularity and uniformity in the case of a skilful worker. A few experiments will interest the pupils intensely, arousing their always lively curiosity, and teaching them the full value of the facts. As they progress in the technique of their craft they will discover that their movements are more educated in quality, and better adapted to their work.

The *education of the movements* is necessary in order to render them effective, to increase their *output*, and to diminish fatigue. The number and rapidity of these movements, and even the effort which they develop, vary according to the individual, and the nature of his work. It will be expedient to determine these movements in the case of *model* workers, highly skilled in their craft, and to explain to the pupils the graphic records of *normal work*. *Disorderly* and *useless* movements, which inevitably give rise to premature fatigue, will be reproduced by means of the *cinematograph*, exaggerating them if need be. *Films* which in this manner display the awkwardness of beginners, of the infirm, and especially of those who have suffered *amputation*, and are provided with artificial arms, will be of considerable value for purposes of apprenticeship and re-education. In view of this teaching by example a few characteristic films, relating to the practice of the principal handicrafts (Fig. 66), will be preserved in the schools.

The conditions of apprenticeship must then be adjusted in such a way as gradually to increase the output to its maximum limit, while the workshop must be so organised as to reduce loss of time and the causes of fatigue to the minimum. But do not mistake me. The object of *economy of time* is not merely an increased production. Before all, it is intended to give the worker *habits of order*, and to confirm the idea that we

should be more useful, to others as to ourselves, if we avoided all aimless muscular efforts, if we kept a watch upon the profitable expenditure of our physical energies.

From these methodical conditions of work a greater efficiency and a more intensive production are obviously to be obtained.

Under such conditions the rules relating to *rest* and *fatigue*, periods of distraction and instruction, and the continued duration of practical lessons, will serve to protect the health.

Whatever the trade, it is the duty of modern apprenticeship to give it a scientific organisation, to select and form the apprentices according to their aptitudes, and to ensure the normal exercise of human activity.

LXXXVI. **Mechanical Considerations.**—From the mechanical point of view, there is, as we have observed, a certain effort and a certain pace, which are conducive to the largest output. Once more it is the graphic method which reveals these, thereby informing us what tasks must be forbidden to the apprentice if his age or strength make them inadvisable. The skill of a worker's movements certainly diminishes fatigue ; but this is not enough, and there is in the elementary operations of labour, the wherewithal to occupy every worker usefully, without exceeding the sum of his capacities.

There is another thing to be considered : the *choice of tools* should be adapted not only to the nature of the work, but also to the age of the worker, so that eventually an *optimum equipment* may be put together, with which the workshop will provide the finished worker. At the close of his apprenticeship the young man ought to be practised in the handling of this equipment, in respect of which his mind has been disciplined as well as his body ; every detail of the practice of his craft, every form of mechanical agency, and every elementary operation, will be deeply engraven in his memory. He will not be made to study one portion of his craft until the preceding portion has been learned, and until he can practise it, to perfection. To exhibit undue haste in the matter of instruction is to waste time. The training of a good workman requires several years ; he follows many masters, endeavours

to profit by circumstances, and sticks to his task with perseverance. The part of science is to diminish the period required by exclusive practice in the workshop.

It is not possible for the apprentice to become familiar with *all* the operations and processes of the workshop or factory. Modern industry does not demand such a mental effort ; which would, for that matter, be all but impossible.

The law of the *division of labour*, which rules the living organism, is no less compulsive in the industrial organism, so that every worker, according to the measure of his capacities, fulfils a given function, and has no need to understand another. I should, however, like to see a general education giving the worker a general conception of his profession ; of the working of the successive organs of transmission, from the manager's office to the work-bench ; so that he would not be launched into the life of action which lies before him without rudder or compass. It is evident that an employer who applies himself to one single speciality will be incapable of giving this complete training. The industrial college is therefore the great organiser of economic prosperity, provided that it proceeds by the inculcation of theory and practice both, the latter coming *after* theory.

It is perhaps as well to remember that mathematics and geometry, indispensable to the mechanic, present gaps which only experiment is able to fill. For example, the theory of friction, of moving bodies, is still far from squaring with the practical data, owing to the complexity of the factors which have to be embraced by an extremely exact science, and the physical properties of bodies. In very simple terms the teacher will explain to his pupils the influence of physical factors, such as the *temper of metals, their chemical composition, resistance, form, etc.*, finding inspiration in the experimental work performed in our higher schools and industrial institutes. Facts are needed, plenty of facts, illumined by a minimum of science.

The suitable arrangement of workshops and factories and the division of labour will enable the apprentice to apply himself to repeating the same detail of work with increasing skill,

with a greater economy of time and effort ; he will seek, if he is intelligent, to adapt himself more perfectly to the conditions of labour whose great importance has been proved to him. I will even go so far as to say that his work will cost him less and less as regards the effort of attention, and will become almost *automatic*. The worker for whom the execution of a task is thus facilitated, by habit, will be able to husband his intellectual efforts for fine work, for the delicate manipulations that unquestionably make the reputation of a factory.

Quality and quantity : we need them both, despite the scarcity of skilled labour and the incoherence of technical methods. The organisation of the apprentice system, and of workshops, on a scientific basis, is imposed upon us by our regard for our future and our reputation.

LXXXVII. **The Duration of Apprenticeship.** *The Workshop.*—The duration of the period of apprenticeship is obviously a difficulty and a source of misunderstanding. Formerly people were lacking in the sense of well-being ; permanent poverty, ignorance, and the lack of liberty had atrophied it. Work, moreover, was ill-paid. Further, the majority of the merchant class took as apprentices their own children, who succeeded them in the business. A regulation introduced in 1673 provided that on the completion of the 17th year the period of apprenticeship should under these conditions be regarded as completed. The father was thus assisted in his task by his children.

But when it was necessary to indenture the apprentice with a master the family no longer received any assistance ; they could expect nothing from their children, but must endure their penury until the end of the term of apprenticeship, which lasted from three to eight years.

According to the statutes in force in France, the period of apprenticeship was as follows :

Three years for drapers and hose-makers, grocers, druggists, confectioners, haberdashers, and jewellers.

Four years for apothecaries, furriers, ropemakers, leatherdressers.

Five years for hosiers, cloak-makers, glovemakers.

Eight years for goldsmiths and silversmiths.

Modern methods have reduced the term of apprenticeship to three or four years. With scientific organisation this period suffices to form very good workmen.

Now the apprentice to-day is haunted by the idea of earning money, as much for himself as for his parents. He no longer understands the necessity of the sacrifice which the learning of a trade requires ; he is too young to understand it, and his family too poor to support it. So we find him leaving his employer at a day's notice because the latter does not pay him enough, or does not regard him as a qualified wage-earner. This desultory apprenticeship makes the worker an outcast and degrades his profession.

Until our industrial colleges are able to open their doors to all our young workers, the employers might turn out good apprentices provided the work of the small workshops were more under control, the reciprocal duties of masters and apprentices being precisely defined ; while if necessary the apprentice might be encouraged by rewards of a material or honorific character. But whether the school or the workshop is in question, the State should endeavour to assist the parents, by agreement with the local authorities, and should influence them morally through the medium of the teachers. It should make a wide appeal to the experience and the zeal of the manufacturers, whom I should like to see upon the councils of all the industrial colleges. And when the apprentice has completed his studies, and is judged worthy of being a workman, he might conveniently be subjected to a year's *probation* in a workshop. In this direction the collaboration of our manufacturers would be of great assistance. The probationers would make excellent workers ; in the factory, above all, they would learn the unavoidable *need of production* of the economic world, and the demands of society ; they would learn, in Taylor's words, " that one cannot sell fine speeches."

LXXXVIII. Social Science and Industry.—This lesson of the economic life of a country ; social science ; the psycho-

physiological knowledge of man : of these the pupils of our great colleges are ignorant, as are the workers trained in our industrial colleges. Both, therefore, should be re-broken to the realities of life by a term of probation in the factory. " Working elbow to elbow with a greasy mechanic, with a workman ignorant of the rules of grammar and a stranger to all the forms of politeness, they will soon be compelled to recognise the intellectual acuteness of these men. . . . In our schools the greater part of the time is devoted to the properties of inanimate materials. . . . Living matter, on the other hand . . . is entirely disregarded ; not so much as an hour's study is devoted to it. The managers, directors, and presidents of our great companies have only one material to work in : *the workers.* The pupils of our colleges will find that the whole of their lives will be devoted to the working of this precious raw material, and they complete their studies at the age of 22, without having heard it mentioned." [1]

In France, after half a century's slumber, we are returning to the science of man, and thanks to the impulse given by the Ministry of Labour, and above all by M. Léon Bourgeois, nothing that concerns the worker is any longer indifferent to us. But while the analytical consideration of the workers is proceeding, in respect of their hygienic and professional requirements, and while their well-being is progressing, it has become a matter of the greatest urgency that the Ministry of Commerce should assist in the work by organising apprenticeship on a scientific basis, and organising it in the schools. The task of the workshop will be complementary. Everything points to the Conservatoire des Arts et Métiers as the centre which should co-ordinate and direct the indispensable undertaking which is imposing itself upon the nation. It combines the scientific authority and the industrial power whose isolated action would be a national disaster.

And around it, receiving light from it, numbers of schools must be added to those that already exist. In Germany, in the city of Munich alone (it contains 520,000 inhabitants), there are sixty schools, of which forty-eight teach commerce,

[1] F. W. Taylor, *Revue de la métallurgie*, Vol. II., p. 648, 1910.

and twelve the industrial arts.   This fact alone tells the State
what its duty is.

There is truly very much to be done, of which these modest
pages can give no idea.   If I were not afraid of discouraging
good intentions, I should subscribe to the verdict of the Ameri-
can scientist, Gilbreth :

"The present system of apprenticeship is pitiable and
criminal, considered from the apprentice's point of view ; it is
ridiculous from the modern point of view ; and there are no
words to describe its futility from the economic point of
view." [1]

[1] F. Gilbreth, *Motion Study*, p. 41, 1911.

CHAPTER IX

LABOUR

LXXXIX.—Labour means the *work* of the workers ; but
it is also used to signify the class of workers as a whole, or the
body of workers engaged upon the same task.   There is a
confusion of persons with the thing, so obvious is it to the
mind that there can be no useful work, nor wealth, nor well-
being without the worker.

Labour, then, is the instrument of economic prosperity,
and for this reason it should be plentiful, well-trained, educated,
and directed ably and with art.

In France labour has always been scarce ; to-day it has paid
the country a very heavy contribution ; its ranks are emptier
than ever.   Already it has been necessary to employ *Italian*
workers, and more recently *Kabyles* and *Annamites*.   In
England the gaps in the workers' ranks may be filled suffi-
ciently by women, but in France these levies of workers from
overseas will necessarily be more frequent henceforth, and I
imagine that French industry would utilise the entire French
and colonial contingent rather than apply to our neighbours.
The fact is that this problem of recruiting labour involves
another problem of very great importance, that of the
aptitudes and the physiological working conditions of men
belonging to many races and hailing from other climates
than ours.   Acclimatisation, however, has not hitherto
formed the subject of any exact investigations ; one may
describe it as abandoned to empiricism all the world
over.

XC. **Italian Labour.**—I shall make only a few brief remarks with regard to Italian labour. As workers the Italians are incontestably very similar to the French, in respect of their mental characteristics and their tendency to acquire similar habits. Their life has evolved in the same world of ideas and feelings. By race, and the hereditary influence of a similar culture, they possess elements of affinity which cement them, more closely than any other people, to our social edifice, the joints being imperceptible.

Better still, the French and the Italian have waged wars in common, and the memories of common glories have, so to speak, set a seal upon an unwritten pact of human cordiality. There have never been, and between these two peoples there will never be, any of those " vigorous hatreds " which we feel for races whose evolution has been abnormal.

Still, the Italian, even in Italy and the southern climates to which he willingly emigrates, lacks energy ; he works intelligently, but with a certain heedlessness ; he does not display the continuity of effort which our modern industries require ; he proceeds by fits and starts, husbanding his resources of energy far more than does the French worker.

Usually, when he emigrates, he lives in a modest fashion ; he is never a feverish worker, but he begins early in the morning and ceases late in the afternoon. The modern system of the organisation of labour, which requires a *minimum of attendance in the workshop and a maximum of production*, would therefore be difficult to apply to the Italian worker. This is an important point, which requires examination. My attention was drawn to it in the course of a scientific mission, with which I was entrusted when in Italy, in 1907.

And for this reason, I do not absolutely accept the doctrine of the eminent Italian sociologist Cabrini, who wrote in 1916 [1] :

" Italy is proud to collaborate in the development of French industry, by providing it with the complementary labour which it lacks, and which we possess to excess. Assuredly the victory of the Entente will arouse in Italy a wonderful

[1] See *Le Journal*, 1 June, 1916.

industrial development. But for a long time yet a large number of workers will continue to emigrate.

" We shall gladly see our compatriots turning toward a nation speaking the Latin tongue, whose temperament is fraternal ; to France, our ally in mind, heart, and political thought. Emigration in Europe is a far more temporary business than emigration to America ; for these emigrants their native country is close at hand.

" However, France and Italy, nations which are essentially democratic, must discipline the movement. It is in your interest not to receive workers who might lower the rate of wages. We do not wish to send you countrymen of ours who might play the part of blacklegs.

" The French State has duties to fulfil in respect of its proletariat, which, having suffered unheard-of sacrifices, remains the admiration of the world. The road must not be barred against those who return from the trenches. France could never permit of the importation of mendicant labour.

" The old theory, which declared that the money sent home by the emigrants is always welcome, whatever humiliation it may conceal, is exploded. Even the Government is discarding it.

" It is important, therefore, to lay down clearly defined conditions on either side. In so doing, we shall confirm the alliance sealed by our arms, both in duration and in strength. Thus the necessity of a labour contract, such as Luzzati proposed, becomes apparent. The emigration treaty, understood as a labour contract, may be summarised as follows :

" 1. The Italian worker in France must enjoy the same liberties as the French worker.

" 2. In any trade union dispute, he must not be expelled until the recognised authorities have delivered judgement.

" 3. Any engagement entered into by French manufacturers must take the form of a common agreement between the Government and the trade organisations of capital and labour."

XCI. **Wages.**—Whatever the character of this foreign participation in the economic work of France, it is none the less true that the supply of workers has seriously diminished, and that there will be an ever-increasing demand for machinery, in industry, commerce, and agriculture. The inanimate motor will continually encroach upon the domain of the living motor ; mechanical cultivation will impose its laws upon the peasantry ; in factory and workshop the machine-tool will reign as a sovereign. And in order to direct and control all these blind and indefatigable forces the worker will be compelled to specialise, to add to his education, to sharpen his intelligence. If apprenticeship does not come to his aid, by adapting him to this delicate task, he will require a long time to get used to it ; his output will be indifferent, and his wages low. For as the employment of machinery and mechanical procedures progresses, greater capacities will be required of our workers, and selection will eliminate a considerable mass of waste labour. An example of the improvement which will be required of labour is afforded by the professions themselves : machinists, watchmakers, electricians, and craftsmen are intelligent, adroit, and expert. They would be still further raised in the social scale if their apprenticeship were organised in the manner already explained.

This is far from being the condition of the bulk of the workers. There are those who labour strenuously and earn little. This is inevitable ; one cannot prevent ignorance from causing poverty. Now more than ever men grasp the fact that they have a right to live, and to live a life that is not a series of hardships and privations. The problem of wages, which comprises many very complex factors, must not disregard this claim, must not confine itself to questions of output. Wages do not require an organism whose needs are regulated solely by the amount of work done, as is the case with a steam-engine, for example. The livelihood of the worker must be guaranteed on a liberal scale ; and by his livelihood we mean the cost of his food, even when he is not at work, during periods of rest, and holidays, and involuntary unemployment ; the maintenance of his health, by means of hygienic home condi-

tions, lodgings, clothing, etc., and the maintenance of the race by means of social hygiene. I say that wages, in the case of every worker worthy of the name, must not be allowed to fall below a certain limit, or the worker becomes the victim of inhumanity. And I declare that whenever a man cannot find a means of livelihood it is society alone that is to blame.

There is in the *division of labour* a scientific solution of the problem of occupying every one on the work that best suits him. And there are so many developments possible to human activity that every worker ought to find his niche without delay. By what aberration do we come to have strikes, when there are rational means of solving the conflicts between capital and labour ? Strikes injure production, and inconvenience employers and workers alike. They will disappear before an organisation which neglects none of the material and moral needs of the workers, and when the laws have ceased to be weapons that have no edge.

XCII. **French Labour.**—Everything that can be said concerning French labour, or almost everything, has been said, and admirably said, by the French economists. It possesses in its own right the spirit of enterprise which enables it to invent, to perfect, and to love progress ; its predominant quality, as is universally recognised, is its love of good workmanship, of accuracy ; routine is repugnant to it, as soon as its defects are understood. This intelligence is less developed among the tillers of the soil, who are more addicted to routine. The French worker readily assimilates new ideas, all the more rapidly as they appeal to his curiosity or appear acceptable. But his temperament is impulsive. Not having enjoyed a protracted education, and being ignorant of method, he likes to dabble in everything, without going deeply into anything. This defect is balanced by the qualities we have mentioned, but it is none the less a real defect. For all these reasons the French schools, whether in town or country, should undertake to direct and favour the exercise of the national virtues in the worker from childhood, instructing the young in all the elements of their craft, plainly

demonstrating the advantages of the modern methods of labour over the ancient, and of science over empiricism. Like the artisan, the peasant also needs the collaboration of an improved technique with his customary methods of procedure. This might usefully associate the activities of his wife and children with his own. This would result in the something resembling the old life of the countryside ; but the old life modernised, made fruitful and productive (Fig. 67).

Fig. 67.—Tilling the Soil in the 18th Century.

The protection of the race necessitates further measures ; workshops, factories, foundries will be so conditioned that none of the rights of hygiene are disregarded therein. Notices will be posted up which will teach the workers the precautions to be taken against possible causes of contagion or poisoning, and the immense advantages of a rational diet, in conformity with the principles which we have already expounded.

It is obvious that this is rather the mission of the labour inspectors, or factory inspectors ; a mission which requires

tact and competence, and which might be simplified by the organisation of evening lectures on the hygiene of labour, at which only experimental instruction would be given. Learned verbiage is the worst of all verbiage ; it drives men away from the truth.

Lastly, the French worker is lacking in the spirit of colonisation. This is probably a result of national prosperity and the Gallic " sociability." Social customs, the spirit of comradeship, and mental inertia keep the Frenchman at home ; but the man who is always *self-contained* escapes this attractive force ; at home or elsewhere, he remains the same. It would be as well that the true French craftsman should to some extent migrate to the colonies, to assist in their economic conquest, in the first place directly, and by setting a living example ; but also by training the native craftsman, for the colonial workers are numerous and of indifferent quality.

The worker who repairs to the colonies requires experience of the native world and a knowledge of the native environment. Further on we shall consider the subject of the *native workman* and his physiological endurance. But all that concerns the environment, that is, the *temperature,* the *effects of the sun,* and the *extreme humidity* of the African regions over which float the French colours, together with all that relates to the diet suited to the colonies, and the nature of colonial life, deserves the fullest consideration. I can only refer the reader to my volume on *Le Moteur Humain* (Book IV.), and to the few following pages. From a practical point of view it is necessary to insist on the necessity of *moderating* the worker's activity, and the expenditure of energy corresponding thereto ; of working at a slower pace than in European countries ; of beginning work early, and ceasing work late, in order to profit by the hours during which the heat is not at its maximum intensity ; in short, of making up in duration what one is obliged to lose in the matter of effort. The meals must include a *smaller quantity of meat,* and *alcoholic drinks must be forbidden,* under penalty of falling a victim to all sorts of possible infections, and of permanently impairing

the resistance of the organism. I attribute to excessive labour and the reckless consumption of brandy the heavy death-rate of the workers who were employed in Madagascar to build the Majunga railway.

Moreover, it is the duty of the European worker to *direct* native labour, which is naturally adapted to fatiguing kinds of work, which will not tax the native's endurance as greatly as it would ours ; and also to *learn* to drive and control the industrial machinery entrusted to him by the colonist. Very soon there will no longer be a single factory or agricultural exploitation without a thorough mechanical equipment. We should therefore train the minds of our workers ; they themselves will look after their muscles.

The Frenchman who repairs to the colonies must abandon some of his European customs, and replace them to some extent by native customs, particularly in respect of food, clothing, and housing, of which we shall say more directly. Otherwise the sudden variations of temperature will soon impair his health, having first diminished his capacity for work. The period required for *acclimatisation* is from *three to four years*, if one leads a regular life, avoiding overwork and intemperance. In the case of Europeans resident in Sumatra, where the mean temperature averages 80·6° all the year round, Glogner gives 4 years as the period of acclimatisation. But it must be added that the previous condition of the subject, his age, and his position, modify this figure. Above all it is important to respect the *cellular habit* in respect of the work of producing energy. Physiological phenomena do not lend themselves to sudden changes ; they demand a slow transition, a gradual training. I will remind the reader, in this connection, that the principal factor of the physical depreciation of the French troops sent out to the colonies is the defective training of the cellular vitality. Even Coulomb had observed the low output of European troops in the colonies. " I have caused," he says, " extensive works to be carried out by French troops in Martinique, where the thermometer is seldom below 68° (to be precise, 77°). I have caused the same work to be performed by soldiers in France, and I can

assert that here, under the 14th degree of latitude, where the men are almost always inundated with perspiration, they are not capable of half the amount of daily work which they can perform in our climate." I therefore persist in upholding the idea that European workers should content themselves with supervising and organising native labour. This latter is adapted to the environment, and Europeans can never replace it without danger at a moment when all European countries are demanding the full activity of their citizens in order to effect their economic recovery from the war.

XCIII. **Native Labour.**—In view of this recovery, it has been suggested that the army of French workers should be reinforced by levies of the natives of Africa, and more particularly of the *Kabyles*. These latter are French subjects. For this reason to begin with, and also because of the services they might render, they merit especial attention. They have too often been observed *from the outside*, through the veil of literature,[1] in the wondering recitals of lovers of the picturesque, and of late in the splendour of heroism. We must also contrive to see them *from the inside*, under all the aspects of their moral and material life, and by the light of their traditions. To become acquainted with them thus is, to my mind, to confer a benefit upon them, for they gain upon acquaintance.

The scientific study of the Arabs occupied me from 1907 to 1909, when I undertook an official mission in the north of Africa. I inquired into the conditions of their work, their strength, and their productive capacity. My numerous experiments tended to emphasise the influence of *alimentation*, *temperature*, and *solar radiation*. I endeavoured to throw some light upon the social and military problem, no less than upon the physiological problem, for there was then much discussion of M. Messimy's interesting proposal for native conscription. I will here summarise my observa-

[1] An excellent example will be found in the article by Charles Géniaux, *Scènes de la vie kabyle* (*Revue des Deux Mondes*, 15 April, 1916, p. 420).

tions, which are scattered through ministerial reports, which the dust of the archives has not defiled, or in technical publications.[1]

XCIV.—Technical and Social Considerations.—*The Kabyles.*

The Arab populations owe to their common Musulman religion the power of the traditions which govern them ; it constitutes a powerful bond between very different races, at all events between those which inhabit the Mediterranean seaboard. The Arab mind is wholly enveloped and penetrated by the religious atmosphere. It takes refuge in a past, which is in truth full of glory and splendour.

I shall speak in these pages of the Kabyle population exclusively. It is of the greatest importance to the world of labour. One encounters the Kabyles in the eastern portion of the department of Algiers, in the department of Constantine, and in various parts of western Africa, above all in Morocco.

From the ethnical point of view we find that there is mention in the Egyptian annals of a Libyan people, living to the west of Egypt ; an autocthonous people, of a fair-haired type. A papyrus dating from 3,000 years before Christ calls this people *Tamahou.* I do not know what this evidence is worth ; but in the time of the rivalry between Rome and Carthage, there was certainly a kingdom of *Numidia,* inhabited by *Berbers,* where the Kabyles are found to-day. Were these Berbers the descendants of a few Phoenician emigrants, contemporaries of the founders of Carthage ? Would they thus be of Semitic stock ? Their type distinguishes them from the Arabs, who were late-comers in the north of Africa. And they have at present no recognisable kinsmen. They are the images of an original which has disappeared.

When Rome had defeated Carthage she appointed her own ally, Massinissa, king of all Numidia, with Cirta or Constantine for its capital. However, the instinct of liberty won the upper hand, and the Roman yoke seemed too heavy to the son of

[1] Jules Amar, *Le Moteur Humain,* Book VI, Paris, 1914 ; *Le Rendement de la machine humaine,* Paris, 1910 (out of print).

Massinissa, Prince Jugurtha. The fiery Numidian horsemen—*Numidae infraeni cingunt*—revolted, and Marius had to fight the army of Jugurtha, which he crushed. In the year 106 B.C. he challenged him, and cast him into prison. The soul of the Berbers was unconquered ; the purity of the race was not impaired ; for no one can claim to rediscover in the Kabyles of Djudjura the well-known features of the Romans, whether physical or moral.

There were renewed assaults and revolts in Numidia, when the torrent of Arab invasion went by, about the year 646 A.D. A Berber Joan of Arc opposed herself to the invader ; the *Kahina* organised the defensive, and won, if not the independence of her native country, at least the admiration of history and the laurels of legend.

Then, in the sixteenth century, came the Turks, whose domination ended with the advent of the French. We will not insist upon events which would not in any case elucidate the mysterious past of the Kabyles, and, more generally, of the Berbers. What survives from this past is the human type with its individual characteristics—the Kabyle, with his intrinsic qualities, which are those we wish to consider. And as the Kabyle is found in Tunis, Tripoli, and Morocco, it is as well to become thoroughly acquainted with him, and to lay bare his thoughts and feelings. Ethnography, in this connection, becomes a valuable means of civilisation.

It is therefore not surprising to learn that the Italian Government has appointed, in order to facilitate the colonisation of Lybia, a commission of specialists whose office it is to analyse all the psychological, physiological, and ethnographical elements, which will assist the work of penetration.[1] I do not know what organisation guarantees the success of the French in Morocco ; but we should have everything in our favour that makes for success. By collaboration and agreement with our Italian neighbours we should bring to bear upon Africa a progressive influence without example in the history of the world.

[1] S. Ottolenghi, *Nuova Antologia,* 1 May, 1914.

XCV. **The Life of the Kabyles.**—Let us return to the Kabyles. They are almost all industrious folk ; they are always busy, either in trade or agriculture. They work with zeal and intelligence, and the other races of Africa find them formidable competitors. I should be inclined to compare them with the *Mozabites,* a Saharan population, equally wide-awake mentally, and undeniably a mercantile people, whose ethnical origin is no less of a riddle. These Mozabites are disseminated through Algeria and Tunis ; everywhere they assimilate themselves to the inhabitants, and by their unusual diligence make a living out of the latter.

The Kabyles generally live in groups ; they have retained their ancient manners, which might be called *Biblical,* in the sense that their constitution recalls the period when Moses divided an unformed people into tribes, and gave these tribes a patriarchal constitution. The old organisation has not been forgotten : the groups of ten, a hundred, and a thousand inhabitants having councils and judges, so that the higher authorities synthetised the lower, and the least hamlet was reflected in the commune, and this in the town. I found these federations, these super-imposed assemblies, these Councils of Ancients, and this family influence, the survivals of remote antiquity, in the organisation of the Berbers. And this again confirmed me in the hypothesis—I do not say the certainty—that the Kabyles are of Phoenician origin.

Down to the tenth levied on the grain, and the hundredth on the flocks and herds ; the assertion of the relations of master and slave as between man and wife—but of a gentle and courteous slavery ; the hospitality shown to the poor man and the stranger ; the respect for the oath, and the keen sense of honour—all the features of life reproduce the existence of which the Scriptures give us a detailed narrative.

Here we have even the explanation of the sedentary life of the Kabyles, and their love of their native country and their homes—as long as they can find the means of livelihood close at hand. If they cannot, they leave their thatched houses, and descend from their hilltops, abandoning an ungrateful

soil and its wasted fields. They repair to the cities, where their labour is well paid and highly valued ; they work by the piece or by the day ; they are economical, honest, and industrious.

Spending little, they quickly attain a comparatively inde-pendent position, becoming small traders or shopkeepers, and succeeding in the majority of trades.

They are not mere tillers of the soil who are lost when they quit the furrow. On the contrary, they love the handi-crafts and arts, and display a certain skill in them. These industrious folk are no less at home before the loom or the embroidering machine than between the handles of the plough. Industrial training would make them model artisans, such as will not be found among their Arab co-religionists. For they are distinguished from the latter by their horror of idleness, and the poverty which it engenders, and they are not super-stitious, nor absolute fatalists ; above all, they possess a prouder sense of their own dignity and liberty.

One feels that they are the true natives, the autochthonous inhabitants, lost in the midst of the human forest which has grown up around them. Their patriotism must not be con-founded with religious fanaticism. I have often been assured, and I have been enabled to convince myself, that faith does not remove mountains in the Kabyle country.

To sum up, the Berbers in general are, in my opinion, an industrious people, united and actuated by interest and honour —which is not really a contradictory statement. They are dominated by a fervent sense of the family. They are ready to make sacrifices, and to undertake any profitable venture far or near ; in short, they possess the qualities of good work-men. And when they have saved some money they return to their own country, resume the interrupted life of tradi-tion, and beside the rekindled hearth, under their own friendly skies, pursue their diligent labours as shopkeepers or agriculturists.

Kabylia, then, has preserved the manners of its ancestors, who, in the famous days of the Roman Republic, created the economic prosperity of the Numidian and Carthaginian

territories. This is one reason why the Italians hope for their own part to profit by their settlement of the Lybian region. In matters of colonisation the past is the teacher and ruler of the future.

XCVI. I. **Anthropological Data.**—The stature of the Kabyle is slightly above the average. Taking 800 Berbers, my measurements gave me an average of 5 ft. 6 in., the average height of the Frenchman being barely 5 ft. 5 in.; the bust is particularly well developed, and the thoracic coefficient, of which we have elsewhere explained the importance, is as high as 0·54, as in all robust and well-proportioned subjects.

The build of the body is rather clumsy, large muscles being attached by very strong insertions to a massive skeleton. The chest is capacious, the limbs large and powerful; the head is irregular, the hair being blond or chestnut, or sometimes of an unbecoming maize-yellow. The Kabyle displays none of the refinement of feature observed in the Arabs; but the countenance is expressive and energetic; the eyes are bright, and the glance penetrating.

The general aspect is a trifle severe, and inspires interest rather than sympathy; it expresses determination and decision. Another physical feature of the Kabyle is the colour of his skin, which is always lighter than that of the other Berbers. The hereditary influence, which augments the immediate action of the solar radiation, and reinforces the pigmentation of the skin, is here very slight; we are obviously dealing with a Mediterranean people, implanted in Africa at a fairly recent period. In this respect Kabyles and Arabs are closely related, forming a group quite distinct from that of the negroid races.

In the negroes the influence of heredity is powerful, and has set its seal upon the anthropological type of the *black race;* there is a profound transformation, in the direction of a diminution of nervous energy and of the intellectual capacities, while a kind of photo-chemical induction is revealed by all the elements of the epidermis : the skin, hair, and beard.

But among the Arabs the pigmentation is slight. I have

elsewhere cited the instance of the cap-makers, who, from father to son, work in the covered quarters of the towns known as *souks;* they hardly ever see the sun, and never become sunburned. Their complexion is if anything white, and they are often rather sickly-looking.[1]

Arabs from the South.   Negro.   Kabyle.
Fig. 68.—Types of North African Natives.

I might mention many other characteristics which differentiate the races which I have observed; their appearance in itself is sufficiently instructive (Fig. 68). I should add that the Kabyles speak French and Arabic, although they express themselves by preference in Berber. It is not for me to hint what this language reveals concerning their history at a

[1] Jules Amar, *Journal de Physiologie*, p. 235, 1908.

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period when it was not as yet confounded with that of any other people. The accent, which is harsh, has by no means the harmony of the Arab tongue. Of what long silent voices is it the remote echo? It is for the epigraphists to inform us.

XCVII. Physiological Data.—The Energy of the Arab.—
The physiological problem relating to the *energy of the Arab* necessitated a series of careful experiments, which I was enabled to apply to nearly 250 persons recruited all over the north of Africa, in order to compare different races and territories.

The strength of the native varies from one town to another, according to the economic conditions. In certain Algerian villages the native is physically depressed, and emaciated by lack of nourishment.

But even when his diet is regular the urban worker is nearly always stronger than the rural worker, the artisan than the peasant. Employing the *dynamometer*, I have found that lightermen, dock-labourers, etc., have given proof of the greatest strength ; next in order come the tiller and the cultivator of the soil ; lastly the shopkeeper or shop-assistant, who lives a sedentary life. The first are capable of an effort almost twice as great as the last, and are able to sustain it longer. This advantage still continues if we compare them with our French peasants, but it disappears when they are compared with the Parisian artisan, who has long been the subject of my investigations.

The consideration of *work* is more interesting than that of strength. I therefore caused my subjects to *carry burdens*, varying from 66 to 132 lbs., at fixed paces, walking on the flat or climbing a staircase. I also made a methodical use of my *braked cycle*, in order to measure the work done by the legs, and to analyse the twofold effects of effort and pace.

It must at once be admitted that the Moors and the Kabyles are superior to all the Arabs in respect of the *amount of daily labour* of which they are capable, and the rapidity of their movements. More nervously constituted, they instinctively tend to work rapidly, and it is difficult to moderate the swiftness

of their movements. The natives of Tunis, on the other hand, adopt a leisurely pace, working with nonchalance, and

Fig. 69.—A Kabyle, as the Subject of an Experiment with the Ergometric Cycle (Biskra, 1908).

it is by no means easy to accelerate their movements. These are noteworthy characteristics.

In industry, and in the army, speed is a valuable factor, and presupposes a small "personal equation," a neuro-

period when it was not as yet confounded with that of any other people. The accent, which is harsh, has by no means the harmony of the Arab tongue. Of what long silent voices is it the remote echo? It is for the epigraphists to inform us.

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In industry, and in the army, speed is a valuable factor, and presupposes a small "personal equation," a neuro-

muscular system which reacts without delay. The Berbers appeared to display the vivacious reaction of the French workman, while the other Arabs displayed the slowness of our peasants, without possessing their tenacity.

By measuring, on the conclusion of several hours of work, the degree of fatigue experienced, and the expenditure of energy, by means of the apparatus already described, I was able to determine the factors of the best daily output (Fig. 69).

In the carrying of burdens with the subject walking on the flat, the results were the same as those obtained in the case of French-born subjects. These results have already been dealt with (Chapter VI.). When it comes to climbing the Arab is less powerful than the European or the Berber. He should therefore be employed on continuous work, necessitating a moderate effort, equal to 44 to 66 lbs., or on agricultural work. The Kabyle alone is adapted to industrial work, and to swift exertion interrupted by short and frequent periods of repose. Considering the amount of work performed in the day, under its various aspects, one may reckon that 5 *Kabyles are equivalent to* 6 *good Arab workers.* The Moors and negroes are in the same category. " Their endurance appeared to be very great, and their output is, as a matter of fact, the highest. This endurance was more particularly displayed by the way in which they resumed the same labour several days in succession without appearing to suffer thereby. Our colonists in Oran are well aware of this ; all or nearly all the labour they employ is Moorish." [1] But if we take into account the intelligence and dexterity of the Kabyle workers, it is to these last that our industries should apply in order to constitute their staffs of operatives. The Moor, and still more the negro, should be employed only as a labourer.

XCVIII. **The Diet of the Arab.**—Native labour is tractable and of excellent quality just so long as its traditions are respected. It goes without saying that its religious practices and its community life must be guaranteed, for nothing can

[1] Jules Amar, *Le Rendement de la machine humaine*, p. 88.

replace them ; moreover, it would be a bad and mistaken action to seek to replace them. The Arab has everything to lose by contact with the European worker and the political discussions of the tavern. We so little understand the noble usage of liberty that we find it expedient to forbid its teaching. But I am more particularly discussing physiological conditions ; and in the first place *the alimentation of Arab workers.*

There is not in the whole of Northern Africa a thatched hut or cottage in which the national dish of *couscous* does not form an indispensable element of the diet. It is a coarse semolina, rolled into small lumps by the combined action of a little water and slightly rancid butter. It is placed in a pot with a perforated bottom which covers the pot or saucepan containing the day's broth or soup ; even the line of junction of the vessels is plastered in order to ensure a hermetically sealed joint. The steam from the broth thus passes through the upper vessel, causing the contents to swell. In this way they are cooked, absorbing the full savour of the broth. The couscous is served in a great wooden dish, the soup or broth being poured over it, while the meat and vegetables which the latter contains in abundance are used to garnish it.

The natives of North Africa are extremely partial to couscous, and the French colonists themselves have acquired a taste for it. It is, in fact, nourishing, light, and stimulates the appetite (for its composition, see the table on p. 109), and the presence of *butyric acid*, due to its rancidity, increases its nutritive value. This observation, already made by Young and Boussingault, is verified by my own experiments, for couscous has yielded me an energetical output *more than* 15 *per cent. greater than that of bread ;* it is therefore more fully utilised by the organism, probably because it favours the digestive secretions both psychologically (Pavloff) and directly. By reason of this appreciable advantage, the elementary habits of the Arab worker should not be modified, except to improve the quality of his meals. Whether employed as industrial or agricultural workers, natives should be treated as they were formerly treated at my instance when campaigning, when

they endured the cold and supported the greatest fatigue.[1] The problem of what they should drink is more important. They ought not to drink anything but water, purified chemically or by boiling, for water is their customary drink ; moreover, their religion forbids the use of fermented liquors. But in spite of this prohibition drunkards are plentiful among them ; even drunkards of distinction, if I may use the term.

Now it is also an Arab tradition to drink tea and coffee, which act as *nervines*, owing to the caffeine contained in each. Coffee the Arabs drink as a decoction ; the grounds settle at the bottom of the cup, beneath a turbid, frothy liquid of an agreeable savour.

Tea is a favourite drink with the Moors ; they drink many cups a day, well sugared, and flavoured with fresh mint. The native displays his hospitality by an invitation to take coffee or tea. So long as the Arab does not consume more than 30 grammes of roasted coffee, or 5 grammes of dry tea in the twenty-four hours, his labours will merely be more active for it, and his efforts more continuous, while all his food will be more fully utilised, the *saving* being on an average 5 *per cent.*

There are therefore *economical foods and beverages*, which men seek after instinctively, and by which one must learn to profit by avoiding toxic doses.

As regards thirst, which is particularly tyrannical in hot climates, and is increased in summer, or by the fatigues of manual labour, or of warfare, I have succeeded in concocting a refreshing drink which my subjects accepted with pleasure. It is a kind of lemonade, whose hygienic, nutritive, and tonic properties are easily explained. Here is the recipe :

Sugar	25 grammes.
Water	1 litre.
Lemon Juice	·025 litre.
Wine (10 per cent. alcohol) ..	·070 litre.

This *vinous lemonade* will replace alcoholic drinks, and its abuse results in no inconveniences.

[1] Jules Amar, *C. R. Acad. Sc.*, 14 December, 1914.

XCIX. Climate and Acclimatisation.—The effects of the climate of North Africa have resulted in a mode of life and a physiological resistance peculiar to the natives, which serve to explain the nature of their diet. The Arab populations are accustomed to live in a temperate region which in several places is torrid. In summer the heat considerably diminishes their capacity for work, for heat and humidity are unfavourable to the contraction of the muscles and the proper functioning of the nerve-centres. However, they stand these unfavourable factors better than we do ; they protect themselves by a training of the organic functions, and by the protection afforded by houses and quarters completely sheltered from the sun. To avoid the symptoms due to excessive perspiration and excessive absorption of the solar radiation the Arabs clothe themselves in *wool*, summer and winter, and in *white wool* because it is but very slightly absorbent, and is permeable to the air, which slowly evaporates the secretions of the sweat-glands. Their pigmented epidermis does not become inflamed, radiating the heat in greater quantities than that of the white man. All these defensive factors are annulled when the Arab is transported to a cold climate, such as that of the north of France. Inevitably the resistance of the organism is lessened. Time is required to restore it to its former level, for acclimatisation is always a very gradual phenomenon ; it progresses slowly, as we have already seen. It results from a series of elementary transformations, in which the living cell plays the essential part ; and it depends on a large number of circumstances. The health is protected against low temperatures by the nervous mechanisms which adapt the intensity of the vital combustion to our needs, and, by means of the vaso-motor nerves, make the circulation of the blood increasingly active. These mechanisms act regularly when one is acclimatised, or accustomed to the cold, and their automatism is not in any way subject to failure. But when the external heat has for a long time condemned them to inaction and rendered them almost useless, they acquire a considerable inertia, and they then require an actual functional re-education. In subjects who are changing from a hot climate to a cold one

the regulating nervous mechanisms have sudden demands made upon them, and are unable to react to the necessary extent, all the more so in that the chemical reactions of the body have become lethargic. Consequently a vicious circle is established in the operations of physical life. The cells are no longer capable of increasing their calorific production, and of protecting the health against the rigours of the cold.

The cruel experiment will be remembered of which the Creole contingents from Martinique and Guadeloupe were the victims. Brought to France by a hasty decision, many of these conscripts quickly perished. The sudden variations of temperature alone were to be blamed. Between the climate of the Antilles and that of France there is a difference of temperature of 22° to 29°, and the hygrometric conditions are very different. The conditions were violently antagonistic to the physiological evolution of these natives.

However, I had advised that in the case of the Creoles,[1] as in that of the Arabs, the classes should be called to the colours in the month of April, and that the men should be sent into barracks in Provence ; or that they should be sent to various portions of Tunis, where they would be ready for employment on our eastern frontier in the September man-oeuvres.

It was this last course which was adopted, unhappily too late, in spite of the opposition of a great newspaper, which was in favour of repatriating the Creoles without more ado. Abstention is a virtue of ignorance.

The same precautions should be taken with regard to the Arab labourers, of whom nearly 20,000 were occupied in our industries before the war ; they should be first employed in the south of France, and should not be sent into the northern provinces until two or three months have elapsed. However, the Kabyles and the mountain folk from the Atlas range resist the cold better, and become accustomed to it more rapidly. They are familiar with the severest winters ; their nerves and muscles have been braced by the cold of the snows. Well fed, and surrounded by hygienic precautions of which they

[1] See, for example, *La Petite République*, 12 July, 1913.

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have not the remotest idea, but which the manufacturer will be able to ensure, they will endure the greatest fatigue and the severest winter without any impairment of their strength.

All that applies to industrial organisation applies with equal force to military organisation. But all would be impossible, acclimatisation and training would alike be useless, were not energetic measures taken against *alcoholism*.

C. **The Cost of Arab Labour**.— Such is the duty incumbent upon Governments and manufacturers at the moment when the economic life of the country is about to overflow its bed, to sweep away the ruin and abomination wrought by man. The reserves of the army of labour must be prepared. Now in Algeria 250,000 natives, or $\frac{1}{20}$ of the population, are in the service of the colonists. They work nearly 12 hours daily, their meals are irregular, and they are exploited by those of their co-religionists who recruit them, and indemnify themselves corruptly and fraudulently for their good offices.[1]

Wages are very low, but the quality of the labour is indifferent. To tell the truth, these men are not acquainted with any craft which reveals a method, or any art requiring study.

The fault of our colonisation was precisely that it disregarded the virtue of apprenticeship and technical instruction, to the point of offering, as a substitute, I know not what empty literature, in which the Arabs indulge themselves while they go short of bread. They love glitter and tinsel, and they have been allowed to believe that degrees and diplomas and the liberal professions lead without effort to officialism. Hence their ardent ambition for civic rights. The Government should have pursued quite a contrary course ; should have multiplied industrial schools, and should have taught in them, together with the indispensable elements of our language, all the useful crafts, industrial and agricultural : not only in order to render our colonies prosperous, to stimulate the activity of those who inhabit them, and often to save them from starvation, the mother of crime ; but also in order to form workmen who might one day usefully be sent to France.

[1] Jules Amar, Report to M. Réné Viviani, Minister of Labour, 3 April, 1909.

The love of work has no other source than the well-being which it procures. The Arab makes an ardent and even a devoted worker or soldier, on the sole condition that his daily bread is guaranteed to him.[1] Our politicians appear to understand this now, thanks to their own observations and the impartial experience of some of our colonists. For nations and races, since the dawn of humanity, have felt their solidarity only by reason of the infrangible chain of interest.

CI.—During the course of the present war a certain amount of Annamite labour has been employed. The Annamites have certain affinities with the Malays and the Japanese; they are intelligent and hard-working, and they make good industrial workers, but in their manners and customs they are far more alien to us than are the Arabs.

To conclude: it is hardly conceivable that I should have written so much of labour without declaring that the right to work is indefeasible. It is obviously the right of all, for the right of each depends upon it; the converse is not true. As I remarked when speaking of strikes, the true solution of the social problem is to be found in the better organisation of the conditions of life, and in well-drafted laws. To be perfect, the work of the legislator should be based upon *experimental science*, and the highly exact teachings of the physiology of work; but, above all, *it should be applied liberally* to all workers, men, women, and children; to the grouped workers of the city as to the peasants lost in the recesses of their hills or valleys. It is by integrity and impartiality that the politician impresses himself upon human societies; sometimes even upon cultivated societies.

[1] Jules Amar, Epistolary Report addressed on 4 June, 1909, to M. G. Clémenceau, President of the Council of Ministers.

CHAPTER X

THE RE-EDUCATION OF WAR-CRIPPLES [1]

I.—FUNCTIONAL RE-EDUCATION

CII.—Science and the human conscience were confronted by a serious problem when it became necessary for them to turn their attention to the labour of wounded soldiers, the glorious victims of this most horrible of wars.[2]

This problem has naturally stirred the noblest minds, and has canvassed all departments of knowledge. I shall not attempt to recall all the efforts which have been made, both in France and elsewhere, to perform useful work in this direction. As a rule inspiration was derived from the rather out-of-date example of the Scandinavian countries. There are, in fact,

[1] I have expanded, in this chapter and those following, my article in the *Journal du Physiologie*, p. 821, 1915, and my lecture on the subject of assisting war-cripples, at which M. Painlevé, Minister of Public Instruction, was in the chair. (This lecture was published as a booklet by MM. Dunot et Pinat, Paris.)

[2] The French language is richer than the English in terms denoting persons who have suffered amputation, who are crippled by wounds or accidental injuries, or whose health has been temporarily or permanently impaired. As some of these terms have no equivalents in English, the translator is obliged to compromise. The adjective *impotent* or *invalid* will be used to denote any person in whom the impaired functions, for anatomical reasons, cannot be restored. The *infirm* subject, on the other hand, may recover the impaired functions. The *war-cripple* may be *invalid* or *infirm*; he has lost a limb, or a segment of a limb, or some other bodily organ. This term will include those who have suffered the *mutilation* or *amputation* of an organ of locomotion. In general, it signifies one who is infirm, or has suffered mutilation, through the agency of external causes; it is used to signify any badly wounded soldier who has suffered functional loss or damage. These terms are necessarily employed to replace a variety of French terms, but, the translator believes, with no real distortion of meaning. —(Translator.)

organisations for the assistance of persons who have lost one or more limbs in Denmark, Sweden, and Norway. The Copenhagen organisation, due to the initiative of Pastor Hans Knudsen, is the oldest (1872). Those of Stockholm and Christiania were created 20 years later. And to whatever country we turn our eyes, we see that those who emulated Knudsen were inspired always by the conception of assisting the lame and crippled, of really *helping* them, and affording them *benevolent relief*. We have here a religious, or if you prefer a moral conception, traces of which are found in the most ancient civilisations. But owing to the lack of a scientific basis, and an ignorance of social problems, no attempt was ever made to provide the wounded soldier with a technical re-education, even after the wars which from 1854 to 1871 drenched Europe and America with blood.

The time has come, I believe, to organise the work of the wounded, in such a manner that each shall fill his true place in the social machine, contribute as best he can to its operation, and thereby advance toward prosperity.

The object of this organisation is therefore *to utilise human capacities rationally*, even when they are diminished, and within the limits of a normal life. " The problem," as M. Viviani remarked, " is to rise from the somewhat inferior water-mark of assistance to that of forethought by means of labour." [1]

CIII. The Necessity of employing Wounded Soldiers.
—This, no doubt, is in its essence a technical and scientific problem, which has been reserved for our own times ; but it also belongs to that order of social questions into which enter, in proportions which I cannot well define, legislative action, and political action, in the higher sense of the term.

We must not indeed forget that on its solution depend both the moral and material future of many thousands of French and English families, and the economic range, as yet so limited, of France. If we wish to stimulate industrial, commercial, and agricultural labour, no effort must anywhere be lost or squan-

[1] From a speech by M. René Viviani, Keeper of the Seals, before the Senate, on 10 March, 1916.

dered. This is the condition of national wealth. We have already remarked that for some years the supply of labour has been growing more and more scanty. Workers and employees have been lacking not only in respect of quality, but also of numbers. What will it be to-morrow ?

Such are the speculations aroused by the problem of our wounded soldiers, and those injured in industrial accidents, in respect of the reserves of energy with which they would endow the nation, were their industrial and commercial aptitudes exploited, so to speak, and reinforced by a methodical re-education, with a view to immediate employment.

To confine our attention to the war-cripples only, 80 per cent. of these are capable of re-education, and could resume their position in the social ranks, secure of earning sufficient salaries and wages. They may be divided into those who can be re-educated unconditionally, who constitute about 65 per cent., and those who can be re-educated conditionally : in the sense, that is, that they require specially equipped workshops, while the former do not ; a difference which involves, in the case of the latter, a certain difficulty in *obtaining employment*, in overcoming the reluctance of employers, who are in general but little inclined to go to the expense of this special equipment for war-cripples. But we rightly desire the employment of these wounded soldiers to be surrounded by all those guarantees which will make it a *durable arrangement*, to the satisfaction of the interested parties.

However, do not let us be the dupes of appearances. The wounded soldier, or the victim of amputation, possesses a capacity for work which is perfectly capable of complete utilisation ; he represents a *value* which is sometimes *integral*. He may even make up for his physical deficiency by an efficacious good-will, which increases his output. This is a psychological fact, by which teachers and employers should profit, for it is undeniable. The French soldier, with whom I have been associating for the last eighteen months, has invariably displayed an admirable spirit of courage, coolness, and resolution. Sometimes a few words of consolation, or better still,

of good advice, were necessary. Never did he refuse to listen to qualified advice.

The numerous wounded soldiers who have not suffered amputation, but display an incapacity for work, which of course differs in degree, are more or less rapidly re-adapted, and are able to dispense with technical re-education ; though they sometimes need to complete their general education, in order that they may turn their attention to office work of some kind ; and such education will in all respects be of value. We may therefore say that barely 20 per cent. of those who have suffered amputation, a very small proportion of wounded soldiers who are completely invalided, and the majority of the blind, will be subjects for relief or assistance only, which in France falls within the province of the Ministry of the Interior.

But the great majority, fortunately, that is, all who are capable of re-education, are waiting for a scientific organisation which shall restore them, by trustworthy paths, to the professions in which each will give his full measure. They understand that to fall back upon public assistance or private charity is a degradation for the man who is still capable of working with hands or brain. And I am in a position to declare that the heroic soldiers of 1914 were always far from entertaining depressing ideas, or of giving way to the instinct of the least effort, although it would have been quite excusable if they had listened to its promptings.

Such are the reasons which have led me to define an efficacious method of re-education, and to expound a programme of action relating to the organisation of the work of wounded soldiers. The many applications of this method and this programme which have been effected in various countries afford proof of their reliability.

CIV. **The General Principles of Re-Education.**—To my mind, re-education should comprise three periods. During the first period, that of *functional re-education*, it is necessary to analyse the movements of the subject, in order to determine his functional condition, to restore, as far as possible, his former

motor capacity, and finally, to make sure that prolonged exertion does not threaten to impair the resistance of the organism.

During a second period, we endeavour to make up for the deficit caused by the infirmity, by a system of orthopaedics ; subjects who have suffered mutilation or amputation will be fitted with suitable *prothetic appliances ;* and then commences the *professional re-education* properly so-called, which is the third and last period. As soon as this is completed we find employment for our wounded soldiers. It is obvious that those in whom some slight infirmity has made its appearance, or those who are capable of immediate orthopaedic treatment, will without delay resume their former vocations. At all events, they could do so.

But if the infirmity is more serious or more extensive, and if it is refractory to all functional re-education, or to any simple mechanical substitution, we must consider the advisability of a *change of vocation.*

The question of a change of profession, which may result in the loss of experience laboriously acquired, of a valuable and often a lucrative nature, is one which must be approached with caution. Nevertheless, re-apprenticeship is occasionally a necessity. It is so in the case of many war-cripples, especially those who have suffered amputation of the arm.

CV. **The Functional Re-Education of the Wounded.**—1. THE INFIRM.—Let us consider the first of these three periods, known as the period of *functional re-education.* In this we deal with the motor capacity of the subject and his *physiological value.* We shall employ, in this connection, the technical methods mentioned above (p. 125), while endeavouring to re-establish the normal mobility of the articulations and the synergy of the muscles. We must not lose sight of the fact that the movement of a limb is accomplished, practically, in a *determined plane,* and that if we can get it to accomplish its maximum amplitude of movement in this plane any other movement is by this very fact made feasible ; the more so as the exercises on the cycle, the cheirograph, or the bulb dynamograph involve the exertion of *strength.*

In any case, we must aim at practical results. Experience shows that the mobility which is gradually restored to the articulations, up to the limits imposed by the necessities of industrial or profession life, the increased strength which is
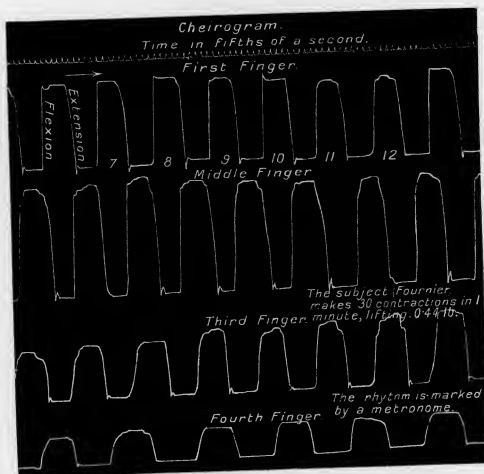
FIG. 70.—Normal Cheirograms of the Fingers.

the correlative of this mobility, and the reparative humoral activity which ensues, form a united and self-sufficing whole. Work is then possible, and will favour the motive power of the organs.

With the ergometric cycle the great articulations are quickly re-educated, within the limits of their *normal and habitual scope*,

whether for walking or the handling of tools. The cheirograph ensures, more strictly and effectively, the mobilisation of the rigidities localised in the fingers or the wrist. The tracings made by the patient, during the progress of the treatment, are compared with a normal tracing (Fig. 70), representing the efforts of the sound hand. The muscles of the hand are finally strengthened and made supple by means of the bulb dynamograph, a simple and rational means of exercise. Cases of weakness or lack of power rapidly improve under such treatment, and in a great number of cases no trace of constraint remains. After exercise massage should be applied, as this assists the process of improvement.

In other cases the infirmity requires long and laborious treatment ; but one should never despair of the resources of training, or, at least, should not despair of obtaining an improvement which will make it possible to re-adapt the wounded soldier to a calling suited to his infirmity.

A large number of men wounded in the lower limbs are obliged to employ crutches, either permanently or for some considerable time. It is important that these should not cause a diminution of mobility ; re-education, on the contrary, should profit by their use, gradually training the legs and accustoming them to resume their normal activity.

Hitherto the types of crutches in use have not prevented the occurrence of 19 cases of paresis among every 100 users of crutches.[1] The majority of those who escape this infirmity owe their escape to the fact that they bear upon the cross-bar in the middle of the crutch rather than on the shoulder-piece. But this pressure of the hands is fatiguing ; moreover, there is less stability of gait. And the employment of *crutch-*

FIG. 71. Adjustable Physiological Crutch.

[1] Tuffier and Amar, *C. R. Acad. Sc.*, Vol. CLXI., p. 302, 13 September, 1915.

sticks, with a spring to support the fore-arm, was only an expedient (Tuffier and Amar).[1]

Later on I devised the *adjustable crutch* (Fig. 71) which gives me complete satisfaction. The shoulder-piece is supported laterally on springs, of suitable strength, which act as shock-absorbers, and bear the weight of the body, imparting to it

Fig. 72.—Investigation of Fatigue in a Subject using Crutches.

a sort of oscillation, which accelerates the movement of propulsion and lessens the axillary pressure. Moreover, the appliance is fitted with a cross-bar which can be adjusted at will, the extent of the said adjustment being 3·6 inches; while the lower portion consists of two tubes, one of which slides into the other, so that the crutch may be adjusted to the height of the user.[2]

[1] Jules Amar, *La Nature*, 29 April, 1916, pp. 287-8.
[2] The average height of a crutch is 50 inches for a man between 5 feet 5 inches and 5 feet 8 inches in height. The cross-bar is 33·5 inches from the ground.

Simple, practical, and very durable, this adjustable crutch fulfils the physiological conditions to be required of any crutch, the mechanical conditions being fulfilled by all models,

Fig. 73.—Tracings made by an infirm Subject undergoing Re-education. The Work represented is filing Metal. (At the end of a fortnight.)

but never by a stick, whatever its form. The wounded soldier must be led, by successive stages, to rely less and less on the double support of the armpits, and to employ the muscles of

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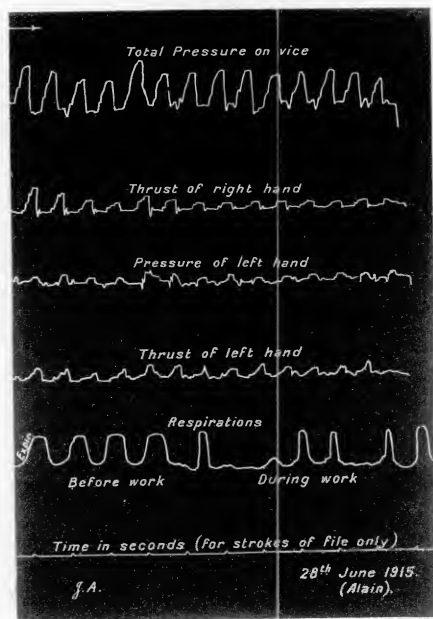
Fig. 74.—The same at the end of a Month.

I am able to assure myself by measuring the respiratory energy.

CVI. Results.—I shall not speak of the results obtained already in the numerous cases in which these principles of functional re-education have been applied. The majority of patients who owe to these principles the restoration of their
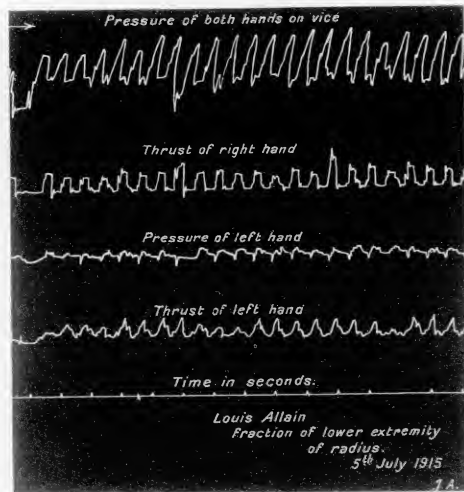
Fig. 75.—The same at the end of Five Weeks.

dynamical capacity have also been re-educated professionally or technically, and in the professional movements performed by them one observes the certainty and the efficacy of the physiological methods which we have just expounded.   I will mention, for example, the case of a fracture of the wrist, accompanied by

the almost complete rigidity of the articulations. Figs. 73 to 75 show how rapidly power and movement were re-established, enabling the subject to resume his work. The cheiro-

FIG. 76.—Work with the File done by a wounded Soldier at the outset of his Re-education.

graph exercises are in this connection of remarkable value. An elongation of the right brachial plexus, whose effects, at the outset, are seen in Fig. 76, left no visible consequences. A complete anchylosis of two fingers (the first and third);

a hand with the fingers flexed like the petals of a bell-flower; the almost complete anchylosis of the right shoulder, resulting from a bullet-wound, which yielded, giving a degree of mobility which enabled the patient to resume his work as ticket inspector

FIG. 77.—Result of the Re-education of a case of complete Anchylosis of the Shoulder.

on the Paris Metropolitan Railway (Fig. 77); a similar case affecting the left shoulder and elbow of a young soldier who was already suffering from scoliosis, but was able to rejoin the army after a few weeks of energetic treatment; rigid fingers; paralysis of the hand, of varying severity; and

the almost complete rigidity of the articulations. Figs. 73 to 75 show how rapidly power and movement were re-established, enabling the subject to resume his work. The cheiro-

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osseous ablations of the fore-arm (Fig. 78) : in all these cases nothing was left of the initial infirmity but traces which were practically negligible.

If I were to give a tabulation of the daily increase of amplitude revealed by the movements of the articulations, and of the muscular strength, scrupulously observed by means of
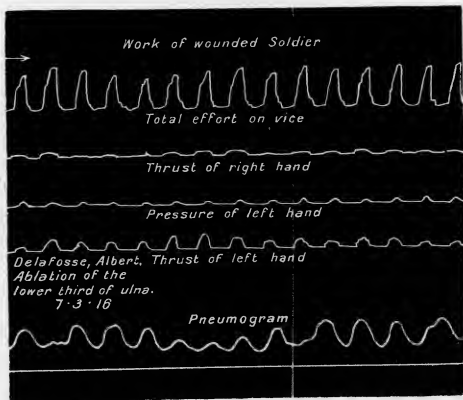
FIG. 78.—Early stages of the Re-education of a wounded Soldier (Ablation of the lower third of the right Ulna).

the arthrodynamometer, I should merely be giving a mass of personal observations, whereas I infinitely prefer the testimony of those who make a study of these important questions, and who write to me in a most gratifying spirit of scientific unanimity.

The only point on which I must insist is that the re-education of the movements must serve as a preparation for the re-educa-

tion of the patient in respect of *useful or professional labour*, and that this must be regulated according to the physical and moral condition of the patient.

While the number of those who suffer from some infirmity due to wounds received in war or to the accidents of the workshop is very considerable, the number of those who have suffered *amputation* is no less considerable. The consideration of such cases forms quite a special study, owing to the necessity of a precise evaluation of the functional loss involved by this or that mutilation, and to the means, which are fairly complex, of remedying this loss by *prothesis*.

CVII.—2. WAR-CRIPPLES.—THE FUNCTIONAL VALUE OF THE STUMPS.[1]—The re-education and the functional value of a stump must be considered from two points of view—that of physiology, and that of prothesis.

Usually nothing is attempted beyond the *estimation* of the *loss of strength* resulting from the amputation. There is no further analysis of the consequences involved by the amputation, or of the means by which they might be avoided. Now it must be remembered that amputation does not merely diminish the muscular activity, considered in its mechanical factors : the force exerted by the muscles, and the bony lever upon which they act. It profoundly affects the *histo-physiological development* of the entire member, even under the most normal circumstances, and in the absence of any complication. Particularly does it affect the sensory system, which, as we have seen, exhibits a strict solidarity with the motor system. The result is a diminution of functional capacity, which no one has as yet attempted to estimate. Yet this estimation is of considerable importance, as a guide to the prothesis and the industrial re-adaptation of the victims of mutilation ; above all when it is admitted that the sensibility of the stumps is susceptible of education to a degree of which absolutely no conception had been formed, as we shall presently see is the case. To accomplish this sensory education of the stumps,

[1] Jules Amar, *C. R. Acad. Sc.*, 29 May and 5 June, 1916, Vol. CLXII., pp. 843 and 887.

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and to develop their functional utilisation to the maximum ; such for two years was the object of my investigations.

CVIII. **The Power of the Stumps.**—In the first place, as I have observed, amputation diminishes the motive power.

The length of the bony lever from the centre of the adjoining articulation is diminished ; the muscular strength is impaired, owing to atrophy and the immobility to which the patient is condemned, often to a greater extent than he should be.

But in what proportions does the power of the stump vary in respect of its length? The more closely it approaches the normal length of the segment, the better the grip of the prothetic appliance, and the more effectual the intervention of the muscular synergy of the member. It is none the less a fact that these two advantages are not uniformly augmented in proportion to the dimensions of the stump. This is demonstrated by the following example :

Let us consider the muscles which flex the fore-arm upon the humerus. The action of these muscles is applied at a distance of about 1·4 inches from the articulation of the elbow, overcoming the total resistance of the fore-arm and the hand, whose effective action is at the centre of gravity, about $6\frac{1}{2}$ inches from the same articulation. It is obvious that if amputation respects the insertion of the muscles which accomplish the useful movements—if, in our example, it leaves a stump of not less than 1·6 inches in length—this latter will possess its total physiological value, which it is the part of scientific prothesis to utilise in a skilful and satisfactory manner. Now this *anatomical measurement* is insufficient ; for, on the one hand, there is no movement in which an entire muscular group does not collaborate with its apparently antagonistic elements ; and in short stumps this synergy, which is physiological, not anatomical, is impaired or restricted. On the other hand, we must take into consideration the *solidity* and *stability* of the adjustment of the prothetic appliance, and this depends on the length of the stump. These two factors are of equal importance in the case of amputations of the lower limbs, owing to the weight and

momentum of the body when walking. In the case of the *upper limbs* the principal factor is *stability* ; its purpose being to make swift and certain movements possible.

It would seem, however, that in the case of stumps which are just sufficiently long to perform their function prothesis offers one advantage over nature ; it replaces the amputated segment by a stronger and lighter segment. But this is not an advantage, for if amputation is effected too high it results in the disappearance of the muscular elements whose strength would have made up for the inertia of the organ ; it enfeebles the phenomena of cellular nutrition and vitality, and, on the other hand, favours atrophy and degeneration. We shall return to this point later on.

The surgeon, however, will rely upon methods of operation which sacrifice the length of the stump in order to ensure that it is more comfortably covered at its termination, and to remove all causes of pain and ulceration.

From these brief considerations it obviously follows that surgery, prothesis, and industrial re-education should be guided by the exact measurement of the power of the stump. Here I will confine my explanations to a description of the experimental methods adapted to this work of measurement.

CIX. **Technical Method of Measuring the Power of Stumps.**—The method employed is very simple. The angular movements of the stump upon its articulation are measured, in degrees, and also the absolute power of the muscles which determine this movement of flexion. By comparing these with the power and the mobility of the sound limb we obtain the *ratio of loss* resulting from amputation.

For such measurements we may employ the *arthrodyna-mometer*. But in order to approximate to the conditions under which the activity of the stump will be exercised, we have adopted the employment of the *dynamometrical splint*, with which, in connection with the ergometrical cycle, we have for the last eighteen months been re-educating amputated limbs.

Fig. 79.—Measuring the power of a Stump (Arm) by means of the Dynamometrical splint.

Fig. 80.—Measuring the power of a Stump (Leg) by means of the Dynamometrical splint.

The stump is adjusted in the splint, whether brachial or femoral (Figs. 79 and 80), the articulation being exactly in a line with the axle. Its maximum movement of oscillation is imposed upon it from the position of extreme adduction to that of extreme abduction, during which movement the axle moves the pointer over the graduated dial.

On the other hand, as we have seen, a ribbon of steel passes over the flywheel ; its tension is adjusted by means of weights, which regulate the friction produced ; in this way a resistance is produced which can be varied at will, and which, moreover, is marked upon a dynamometer. The product of the friction and the distance travelled by the periphery of the flywheel gives the *work performed*. The duration of the oscillation being known (it should be the most rapid and the most ample obtainable) we can reckon the *power developed* per minute.

This functional power of the stumps differs in different subjects. Therefore, in comparing the sound limb with the amputated limb, we should make the same measurements in the case of a number of subjects, and from these deduce the average values. From observations conducted in the case of 200 persons who had suffered amputation of the upper arm, fore-arm, thigh, or lower leg, we have calculated the functional power of a stump of a given length, the length of the normal segment being assumed to be 100.

CX. Data Resulting from Measurements of the Power of Stumps.[1]

AMPLITUDE IN DEGREES.

A.—UPPER LIMB.

(a) *Upper Arm.*[2]

		Anterior.	Posterior.	Total.	Tot. Power.
32 to 13 centimetres	...	140°	90°	230°	100
12 to 7 ,,	...	100°	52°	152°	64
6 to 5 ,,	...	85°	45°	130°	44
4 ,,	...	55°	25°	80°	9

[1] It is needless to remark that the work performed and the length of the stump enable us to calculate the force exerted by the latter.

[2] Length from the armpit.

Fig. 79.—Measuring the power of a Stump (Arm) by means of the Dynamometrical splint.

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CX. Data Resulting from Measurements of the Power of Stumps.[1]

AMPLITUDE IN DEGREES.

A.—Upper Limb.

(a) *Upper Arm.*[2]

		Anterior.	Posterior.	Total.	Tot. Power.
32 to 13 centimetres	...	140°	90°	230°	100
12 to 7	,, ...	100°	52°	152°	64
6 to 5	,, ...	85°	45°	130°	44
4	,, ...	55°	25°	80°	9

[1] It is needless to remark that the work performed and the length of the stump enable us to calculate the force exerted by the latter.

[2] Length from the armpit.

(b) *Fore- Arm.*[1]

24 to 12 centimetres	...	...	...	Flexion of 140°	100
11 to 7 ,,	...	...	...	,, 125°	68
6 to 4 ,,	...	...	...	,, 95°	40
Less than 4 centimetres	...	...	,, 90°	negligible.

B.—Lower Limb.

(a) *Thigh.*[2]

		Anterior.	Posterior.	Tot l.	Tot. Power.
40 to 18 centimetres	...	110°	40°	150°	100
17 to 10 ,,	...	70°	32°	102°	62
9 to 6 ,,	...	55°	30°	85°	38
5 ,,	...	40°	28°	68°	24
4 ,,	...	...	incapable of utilisation.

(b) *Lower Leg.*[3]

38 to 17 centimetres	...	...	...	Flexion of 125°	100
16 to 7 ,,	...	...	...	,, 110°	73
6 ,,	...	...	...	,, 90°	negligible.

The values given in this table present a certain analogy and convey a good deal of information.

In particular we note that *no stump less than 4 centimetres (1·6 inches) in length can usefully be fitted with a prothetic appliance.* If the length of the stump is from 4 to 6 centimetres (1·6 inches to 2·4 inches) in the case of the fore-arm, and not less than 9 centimetres (3·6 inches) in the case of the thigh, the prothetic appliance should be so devised that neither the amplitude nor the strength available is diminished thereby. We shall consider this point later on.

CXI. **Histo-Physiological Modifications of the Stumps.** —But the power of a stump does not express the whole of its functional capacity. The solidarity of the nerve-elements, sensory and motor, reveals itself in such wise that the least hypo-aesthesia diminishes the dexterity of the movements and the output of prothetic appliances. Accordingly, it is important that we should know what changes are produced by amputation in the *histo-physiological* conditions of a stump. These are *trophic disorders* and *sensitive disorders.*

[1] Length from the crease produced on the inner face of the arm by the flexion of the elbow-joint.
[2] Length from the inguinal crease.
[3] Length from the articulation of the knee.

A. *Trophic Disorders due to Amputation.*—Of the trophic modifications the most rapid is that of the muscular fibres ; their diameter is reduced ; and those which have been bisected form new tendinous insertions at the expense of their contractile substance. The result is that their power of contraction is more restricted ; that is, there is a loss of absolute strength ; while as the insertion is nearer the articulation a greater effort is necessary for the execution of a given movement.

Normally the shortening of the bony lever actuated by the muscles should have led to an increase of their diameter. That this is not the case in the stumps of amputated limbs is due to the fact that the nervous elements, without which the vitality of the muscular fibres disappears, are the seat of a degeneration which is favoured by the absence of movement. This degeneration is accompanied by fatty infiltrations, in the nerves as well as in all the cells. The transverse section of the stump reveals, at its edges, in the region of the flaps, where these exist, very strongly marked signs of these histological transformations. They are extremely inconvenient when it comes to providing the patient with prothetic appliances, since the latter obtain a hold without provoking the sensibility, which for the performance of the ordinary actions of everyday life one would wish to preserve unimpaired.

More slowly than the other tissues, those of the skeleton evolve in their turn. Our observations of experiments made upon frogs during the last six months or so have enabled us to verify the production of a certain *osseous rarefaction* in the stumps of amputated limbs, the *density* of the divided femur being less than that of the intact femur. Moreover, investigations of longer continuance, in the case of animal species capable of great muscular efforts, proved that the layers of spongy tissue change their character, and adopt a new mode of resistance. We must therefore always remember that the power of the stump is diminished and its vitality decreased.

CXII.—B. *Sensory Disorders due to Amputation—Sensory Education.*—From the standpoint of nervous development, every victim of amputation possesses a *diminished field of*

sensibility. The sum of these sensations originating in the cutaneous surface of the mutilated member is not sufficient to maintain the normal rate of cellular reaction; hence the trophic disorders observed; for the phenomena of nutrition are indirectly stimulated by the external impressions which evoke the motor nerve-impulse.

Moreover, the *sensibility of the stumps* upon contact or under pressure is *diminished,* and the nerve-centres, disconnected from their normal anatomical connections, interpret the sensations wrongly.

Sensibility of the Stumps.—As a matter of fact, the transversal surface of the stump is by no means very sensitive to touch. An exploration of this surface by means of the *aesthesiometer* (Weber's type) with two ivory points, shows that the points must be separated by about 20 millimetres (four-fifths of an inch) before they become perceptible, whereas in the fingers a separation of 2 millimetres (about one-twelfth of an inch) is sufficient. Despite this hypo-aesthesia, the section is more sensitive in the neighbourhood of the cicatrix than on the lateral surface of the stump. Thus, a subject whose arm had been amputated about the middle of the humerus yielded the following data: Near the cicatrix, 17 mm.; at the edges of the extremity, 22 mm.; on the lateral surface, 30 mm.

When a terminal flap exists, its sensibility is uncertain; sometimes it is negligible, in which case fatty degeneration may be observed.

A second important feature is that of the *lateral transfer,* or *referred perception.* A point on the transverse surface is touched; the tactile sensation is perceived at a point of the lateral surface, situated on the generator adjacent to the spot which is touched. In proportion as the amputation is more recent and the stump more atrophied it is perceived further from the plane of section.

The phenomenon of the transfer is constantly observed in subjects who have suffered amputation of the arms and legs, but it is by no means definitive.

The *education* and *the sensory re-adaptation* of the stump

correct these errors of localisation. They are effected by means of suitably regulated exercises. The patient actuates with his stump the *splint of the ergometric cycle,* overcoming resistances which are gradually varied. Intelligence and attention will help him to appreciate these variations.

Fig. 81.—Sensory Education of a Subject who is Blind and has suffered double Amputation, by means of the weighted Bracelet.

But we must continue with an exacter method, employing the bracelet with *adjustable weights.* This is placed at the extremity of the stump, and weights are placed upon the suspended disc, and are diminished daily. The subject, whose eyes are blindfolded, has to say whether weight has been added or removed, whether it is still the same, whether it has been diminished, and by how much—all information

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which has to be elicited from the patient. Then the bracelet is moved along the stump, in order to explore its sensibility.[1]

By means of a small *pressure dynamometer* it is discovered that the stump reacts in varying degrees according to the point stimulated. In the neighbourhood of the cicatrix the perceptible pressure is, on an average, 20 grammes less than that which is required on the edges of the stump, and 75 grammes less than that required on the lateral surface. And the phenomenon of referred perception is observed as long as the absolute value of the pressure does not exceed 300 grammes. Sensory education overcomes this hypo-aesthesis, notably to the advantage of the *blind*, for whom a special method must be employed (as will be seen further on).

CXIII. **Weir-Mitchell's Phenomenon.**[2]—There is another peculiarity to be observed in those who have suffered amputation, which Weir-Mitchell was the first to insist upon (1867). I am referring to the *illusion* suffered by all such persons, to the effect that they can still feel, and still possess, the portion of the limb which has been amputated, which they feel to be *nearer* the stump than it was in reality. This illusion is preceded by a sensation of tingling or *formication*, the seat of which is close to the cicatrix.

Accepting the *lifelong persistence* of this hallucination, the American scientist concluded that the origin of all our actions is *central*, cerebral, and not in any wise peripheral. We conceive and determine our movements in the brain, nothing external to us provoking them ; the sensibility has no part in them.

My experiments are far from confirming the views of Weir-Mitchell. The phenomenon described by him is not permanent ; re-education causes its disappearance in a few months, and the resumption of daily work destroys the last traces of it.

It is during inaction, in hours of idleness made gloomy by anxiety, and in wet weather, that the painful sensation of

[1] *C.R. Acad. Sc.*, 2 and 16 October, 1916, Vol. CLXIII., pp. 335 and 401.
[2] Weir-Mitchell's *Lesions of the Nerves.*

the "phantom" limb occurs. What is more, the patient feels *only* the *terminal segment*, the *hand* or *foot*, but never the intermediate segment ; and he is conscious of it such as it habitually was, *in the dynamic condition*, the hand gripping the tool, the foot set in the position which the patient's calling requires. He is not conscious of formication during the night, but the latter feeling awakens with the memory of industrial or professional life, so that it results from a mental and a physiological cause.

Weir-Mitchell's phenomenon admits only the first of these causes. But the second is the more essential, and is related to the *sensori-motor cycle*. By the very fact that the sensory education of the stump results in the cessation of referred perception and the illusion of the absent member, completely correcting the reference of sensation to its external causes, there is no possibility of doubt that sensibility governs all our actions ; the periphery of the organism is physiologically connected with the nerve-centres. Thus it is that the child forms an accurate conception of *actual* space and its relative distances.

The theory of formication is supposed to be as follows :

Impressions may travel along any sensitive path. For example, if the hand is amputated impressions from the fore-arm and upper arm reach the nerve-centres. The motor reaction emanating from the latter is checked at the termination of the motor nerves, which are here interrupted by the amputation. Now the section established by this amputation is a surface all of whose nervous elements are deadened, and more often than not affected by degeneration ; such a surface constitutes a *screen*, and the motor reaction communicates its impulse to the *recurrent fibres*, and this gives rise to a special formication.

CXIV.—Experience shows, then, that the re-education of stumps *improves* their physiological condition, re-adapts them, and lessens the danger of nervous degeneration. It enables the stumps to act upon the prothetic appliances fitted to them with a perfectly graduated force, and an im-

proved utilisation of the tactile sense and the muscular sense. This is highly important, particularly in the victims of a double amputation, or those who have lost their sight as well as one or more limbs.

To these advantages, which are of great value in ortho-

Fig. 82.—Examination of the organic condition of a War-Cripple.

paedic surgery, we may add the moral advantage of bestowing upon the war-cripple a certain sense of energy, and a feeling of hope as regards the future.

CXV. The Re-Education and the Organic Condition of War-Cripples.—Re-education is not confined to the motor organs ; it is being extended increasingly to all the agents of human activity ; to those which dispense energy (the heart and

lungs) and those which maintain our relations with the outer world (the senses). It is indeed possible, as we have seen, to re-

Cardiogram of War-Cripple.

Resting (before experiment)

About the 7th minute (Still working)

About the 13th minute (do). The subject (Court) has had his right arm amputated above the elbow. He pedalled 13 minutes at 168 revs. with 4 4 lbs on the brake.

On stopping after 13 minutes work.

Time in fifths of a second   23rd December 1915.

Fig. 83.

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Cardiogram of War-Cripple.

Resting (before experiment)

About the 7th minute (Still working)

About the 13th minute (do). The subject (Court) has had his right arm amputated above the elbow. He pedalled 13 minutes at 150 revs, with 4 4 lbs on the brake.

On stopping after 13 minutes work.

23rd December 1915.

Time in Fifths of a second

Fig. 84.

adapt the sense of *touch*, a sense very highly developed in the blind, and a sense upon which the prothesis of the upper limbs is very largely dependent.   The sense of *hearing*, diminished as

the result of accidents to the outer ear, appears also to be capable of substantial improvement ; but of this I have no personal experience. And everybody knows that the sense of *sight* is susceptible, after appropriate treatment, of remarkable ameliorations.
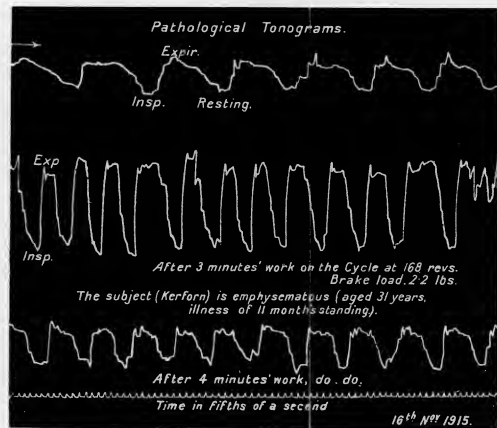
Fig. 84.—Respirations while Resting, while Working, and after Working, in an Emphysematic Subject.

What I can assert in this connection is, that most of the senses are blunted as a result of nervous disorders or shock, and also as a result of traumatisms of the skull. When the patient has recovered we find the senses recovering their acuteness, under the influence of constant and intelligently supervised exercise.

But we must understand how to detect not only the deficiencies of the sensorial organs, but also the affections of the heart, the vascular system, and the lungs, in order that we may with certainty determine the physical aptitude of the war-cripple, and his degree of endurance. In the first place there should be a preliminary examination with reference to the thoracic and morphological characteristics. Then comes the clinical examination. We then consider, as objective documents, the *pneumographic* and *cardiographic tracings* obtained after fatiguing exercise on the ergographic cycle. This exercise usually takes the form of a ten minutes' " ride " at a pace of 200 revolutions per minute, the resistance of the brake being 6·6 lbs. (Fig. 82).

The tracings reproduced in Fig. 83, for example, which were obtained before, during, and after such exercise, show that the *cardiograms* of patients who have suffered a *recent amputation* are of feeble amplitude ; the *systoles* are lacking in vigour, and as a result the *arterial pressure* is diminished. But this phenomenon is ephemeral ; re-education restores the heart to its normal mode of action.

In the lungs we observe dyspnoea, with frequent and profound respirations, whenever the ventilation is insufficient, or is obstructed by a physiological cause (Fig. 84). In this connection the subject may even practise *respiratory gymnastics*, combined with medical treatment. I consider that the organic condition of our war-cripples, if we do not wish it presently to deteriorate, should be kept under observation by physicians who would act both as re-educators and clinicians ; perhaps more particularly as the former.

It still remains to accomplish the diagnosis of the *mental condition*. The present war has drawn the attention of all to this subject. Terrible in its effects, it has shaken the higher nerve-centres, and has often disordered the proper functioning of the brain. It has predisposed thousands of wounded soldiers to *intellectual disorders*, *phobias*, *hallucinations*, and various *psychoses* (disorders of the will) which are as yet obscure.

If we devote ourselves to the task of re-educating infirm and crippled soldiers, our principal pre-occupation must

consist in guarding them against their own *moral dejection*, and in restoring their self-confidence. To learn how to speak to them, to sound their preferences, to divine their tastes, and to enable them to realise the progress of their re-education, its progress, and the merit of work ; herein lies the whole of the veritable art of re-education, in which human science and our duty to the nation are combined.

Accordingly, before entrusting one of our wounded soldiers to the workshop or the office, before fitting him with a prothetic appliance, it is indispensable that we shall have obtained the maximum improvement in his functional condition and his *resistance to fatigue* ; we must have analysed the movements which he is still capable of making, in respect of precision, amplitude, and force. These data furnish information useful to employer and employed alike ; they will inspire them with all the confidence in science which the latter deserves, and which make it the highest form of social economy.

CHAPTER XI

THE RE=EDUCATION OF WAR=CRIPPLES

II.—Scientific Prothesis

CXVI.—1. Principles.—Let us now consider the problem of *prothetic appliances ;* one of the most important of all the problems which are included in the subject of professional re-education. Our makers of prothetic appliances will have to make greater efforts to adapt their appliances to the work of the war-cripple. The essential object of prothesis, indeed, is not to replace a lost limb or segment of a limb, but to *supplement or replace a lost or badly impaired function.* Although by definition prothesis is anatomical, it is, in fact, physiological and utilitarian. While copying nature, it is not the slave of nature, because it is obliged *to proportion the weight and the dimensions of the artificial organs to the muscular power still available.*

As the etymology of the word informs us, prothesis (from the Greek πρόσθεσις = addition) consists in the addition of mechanisms or appliances which restore or facilitate the exercise of the original function.

It must therefore consider the functional condition ; it must even favour its improvement ; and it must protect the stump from all causes of pain and fatigue. The last point lies, of course, within the competence of the surgeon ; he alone can judge of the possibility of saving a maximum *useful length* of the member, and of saving it in such a condition as will allow the prothetic appliance to be *firmly attached* to it ; he, too, is in a position to make sure that nothing remains in the stump, neither bony splinters, nor traces of

irritation or suppuration, nor any cause of pain, which might delay the intervention of prothesis. Five or six weeks must be allowed to elapse after complete cicatrisation before an appliance is fitted to the stump ; as a rule the latter retracts and diminishes in volume, becoming firmer. Exercises, *suitably regulated*, set it developing in the right direction ; they revive the humoral activity and maintain the cellular vitality by which the foci of osteitis and the menace of degeneration are destroyed. The limb is then ready. Prothesis will now set to work, and all the ingenuity of mechanical science will be required for the task of devising the artificial organ and adapting it to its function. *Ingenuity* is the right word ; for, while he may utilise the principles of cinematography in the ordering of component parts, the maker of prothetic appliances must have that love of experimental research which surprises and imitates natural actions.

Fontenelle relates that a priest, Father Sébastien, used in his time to excel in this art of delicate and ingenious invention. So great was his reputation that a Swedish gentleman even repaired to Paris to ask him, so to speak, to restore his two hands, which a cannon-ball had carried away, nothing being left but the stumps of the fore-arms. It was therefore necessary to make two artificial hands, controlled by the said stumps, whose movement would be transferred, by suitable wires, to flexible fingers. Father Sébastien was not dismayed by the task, and, it is said, submitted some interesting specimens to the Academy of Sciences.

Profiting by all the progress accomplished in the mechanical arts, it is possible, in this connection, to carry virtuosity to a very great length. But there are principles from which prothesis must be careful not to depart. We may formulate them as follows :—

(*a*) To devise prothetic appliances which can be firmly and strongly attached, without impeding the movements involved, or those of other articulations ;

(*b*) To adapt these appliances, in respect of weight and dimensions, to the strength of the stumps ;

(*c*) To fit appliances for the upper limbs with an organ of

prehension which will permit of protracted and varied employment.

These threefold conditions guarantee *strength, simplicity*, and a *good output* in prothetic appliances ; resulting in the always desirable employment of human energy in professions to which it might have seemed that the war-cripple could never gain access.

CXVII. **The Utilisation of the Stumps.**—Let us analyse the problem more closely. Whether a *leg* or an *arm* is in question —for the moment I am neglecting the lesser mutilations— the *aim* is to fit upon the stump an appliance which replaces the amputated segment, and which is mechanically controlled by the muscular force still available. Now anatomy and physiology teach us what movements have been suppressed, and must be re-established, and in what measure the stump will be able to produce them, as regards their force and amplitude. These details are familiar ; we will only remark that the *articulation* of the *shoulder* and that of the *hip* are the *fundamental* articulations ; each controls the whole member of which it forms a part, and ensures its effectual action ; the muscles actuating these joints possess a development which enables them to assist in distributing the motive force to the lesser segments.

There is always a *limit* to the rational utilisation of the stump.

For the *upper limbs* this limit is reached in the case of amputations which leave a stump of not more than two inches in length, measured from the line of the armpit. At this level the muscles of the shoulder, especially the deltoid and the infra-spinatus, are incapable of effecting, by their contraction, all the requisite displacements of the bony lever into which they are inserted.

In those whose *fore-arm* is amputated the strength of the upper arm is evidently complete, unless there is some accident of a pathological order, such as anchylosis or atrophy. The strength of the fore-arm may be regarded as sufficient when the stump measures two inches from the internal crease of the elbow ; it is complete when the stump is four inches and

more in length, the flexion, supination, and pronation being complete. If the stump is less than four inches in length the loss suffered by the humero-radial articulation is difficult to make up for. However, it will hardly be felt in the ordinary actions of everyday life, as long as the shoulder retains its complete liberty of circumduction.

Anchylosis of the elbow, on the other hand, creates a functional impediment of a somewhat serious nature, as it deprives this articulation—which is mobile rather than powerful—of the possibility of guiding the movements of the fore-arm, by automatically modifying its inclination toward the upper arm. This defect is revealed by a painful oscillation of the trunk and shoulder.

CXVIII.—In the *lower limbs*, the *mobility* of the stump of the thigh is not of absolute importance : it is enough that it should guarantee the possibility of *walking* by allowing an angular movement of 30°. Physiologically, any stump which measures more than two inches from the inguinal crease will fulfil this condition. But its *length* is not a matter of indifference in connection with the wearing of a prothetic appliance. If the lever is too short it will diminish the adhesion of the thigh-piece, and may compromise the solidity of its attachment. This will compel us to resort to more and more powerful means of attachment, which we shall seek, if possible, in the pelvic girdle. If the points of attachment are too remote they are defective, because in the long run they create an asymmetry of the body and excessive fatigue, and because they interpose, between the appliance and its attachment, a mobile system, subject to deformation, in which there will inevitably be a certain amount of play. Therefore the factors of a correct prothesis are *short paths of transmission and a symmetrical distribution of the surface of insertion.*

The same remarks apply to the lower leg. However, if the knee-joint controls only a small stump (as in the case of amputation at the so-called " point of election ") the appliance will none the less allow of normal locomotion. Any segment less than 2·8 inches in length will be unsuitable for walking

with a free knee-joint ; it will be necessary to flex it and to *walk on the knee*, as in the case of intra-condylar amputation.

CXIX.—The stumps resulting from *minor mutilations* are those of the fingers, the metacarpus, etc. Here the functional value demands the closest attention and careful experiment. Let us suppose that the phalanges are lost. In the four fingers of the hand—not counting the thumb—the two terminal phalanges are replaceable ; but the sensibility is not replaced, or rather it is only partially replaced, by the contact of the prothetic appliance with the stump. Or if the four fingers are completely lost it will still be possible to replace them by artificial segments affixed to the metacarpus. Any mutilation nearer the wrist complicates the prothetic apparatus, *but should never make it impossible to devise a block of artificial fingers which can be opposed to the thumb.* The patient will therefore retain the means of employing his hands with a sufficient degree of dexterity.

It must always be remembered that the office of the hand is, in the great majority of cases, that of a *vice* or pair of *pincers ;* the thumb is opposed to the joint action of the fingers ; hence its Greek name of *anti-hand* (ἀντίχειρ), which is more expressive than the Latin root *pollere*, which means *to be powerful.* In the function of the thumb there is a geometrical element, that of opposition, and a dynamic element, that of the strength which the hand would cease to exert without it.

A reduction of the *number* of the fingers affects both the foregoing factors ; it impairs the *solidarity* necessary for precision of movement, and the distribution of the efforts applied to a given tool or instrument.

If we reckon the *crushing effort* between thumb and index finger to be 15·4 lbs., it will be 22 lbs. with the added effort of the middle finger, and 26·4 lbs. if the third finger is added to the first and second. The fourth finger adds practically nothing to the crushing effort. Its function is one of guidance.

As for the thumb itself, it can be replaced by an artificial thumb, without a joint to the first phalange. But in the absence of the metacarpal bone its function is greatly diminished.

CXX. Mechanical Factors.—From another point of view the functional value of the stumps is connected with the *mass* and the *dimensions* of the prothetic organs, the mechanisms which they have not merely to control, but, in the first place, to carry. On principle we shall distribute the heavy parts of the appliance *around* the stump, either supporting them directly by means of the latter, or assembling them around it. The less weighty portions, on the other hand, will be at the periphery.

It is obvious that hollow organs and parabolic forms present great advantages in this respect. Nature creates such in the branches of trees and the pinions of birds.

The maximum of resistance with the minimum of mass is a fundamental law of the construction of the artificial limb, whose meaning is explained by the absence of multiple motor forces. In the lower limbs, for example, the muscles repeat and co-ordinate their efforts, from the coxo-femoral articulations to the articulations of the foot, so that it is not merely the *pelvic musculature* which actuates the various segments of the limb. Now in the artificial limb a *single* control, a *single* motive force, is often required to actuate *several* artificial *segments*. We shall therefore seek as far as possible to reduce the mass, that is, the inertia, of these segments, and also the *radius* of the round moving parts, the length remaining what it should be anatomically. Under these conditions we diminish what the mathematician calls the *moment of inertia* of the limb. Finally, mechanical considerations, which I cannot enter into here, show that the *centre of gravity* of the apparatus should always be close to its axis of oscillation.

In the case of a well-proportioned man of average build, the segments of the body give the following numerical values :

Segment of Body.	Weight in Kilogrammes.		Per cent. of Body Weight.		Length in Metres.		Position of the Centre of Gravity [1] (Metres.)		Moment of Inertia.[2]
Head ...	4·590		7·06		0·16				
Upper arm	2·180		3·36		0·35	0·165	0·32	0·00244	
Fore-arm	1·480	× 2	2·28	× 2	0·24	0·100			0·0247
Hand ...	0·550		0·84		0·19			0·00350	
Thigh ...	7·530		11·58		0·45	0·200		0·01500	
Lower leg	3·425	× 2	5·27	× 2	0·44[3]	0·185	0·38	0·00800	0·1003
Foot ...	1·165		1·79		0·26	0·112		0·00070	
Trunk ...	27·750		42·70		0·72				
Totals ...	65·000 kgs.		100·00						

These data indicate the extreme limits of weight ; but we must be guided absolutely by the functional power of the stump, determined as we have already explained.

For the *choice* and the *properties* of the materials employed in the construction of prothetic appliances, I must refer the reader to *Le Moteur Humain* (Book I.). It is enough to remark that the resistance of these materials (wood, leather, metal) is especially important in the case of the lower limb, which has to support the entire weight of the body in walking, and which, at rapid gaits, has to stand a stress 25 per cent. to 30 per cent. greater than the weight of the body. The necessity of reducing the inertia of the thigh-pieces makes us advise the employment of materials which are specially tough and light, such as three or four-ply wood, consisting of very thin layers, firmly glued, or papier-maché, or *duralumin*, which has the following characteristics :

Density ..	..	2·8
Limit of elasticity	..	27 kgs. per sq. mm.
Tensile strength ..	..	36 kgs. per sq. mm.
Elongation on rupture ..	..	17 per cent.

Sheet Steel, 1 mm. to 1·5 mm. in thickness ($\frac{1}{25}$ to $\frac{1}{18}$ in.) will answer the same purpose. But the metallic sonority of steel

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[1] Measured from the superior or nearest articulation.

[2] This is the product of the mass and the square of the radius of rotation, a product which enters into the calculation of the *energy of rotation* of a body. (See *Le Moteur Humain*, p. 54, *et seq.*)

[3] Including the height of the foot (6 centimetres).

should be avoided by means of a strongly adhesive covering of parchment.

Steel will always be employed in the construction of working parts. Prothesis demands steels whose composition should be more or less as follows :

Carbon	..	..	..	..	0·35 to 0·45
Manganese	..	..	..	..	under 0·70
Silicon	..	..	..	..	,, 0·20
Sulphur	..	..	..	..	,, 0·05
Phosphorus	..	..	..	..	,, 0·05

The metal will be heated to 850° ; it will be allowed to cool in the open air and hardened at 750° ; it is then brought back to 500° for a space of 30 minutes.

Its tensile strength is 100 kgs. per square millimetre, the elongation being 10 per cent.

In my opinion, the use of *pure* aluminium should be abandoned ; it tears easily, is difficult to work and to weld, and is lacking in toughness.

This survey, which is necessarily extremely brief, of the objects and principles of scientific prothesis, will enable us now to glance at its applications.

CXXI.—2. APPLICATIONS.—The capital point in prothesis is the *anatomo-plastic* application of the appliances. This demands a sound knowledge and a long experience of the subject.

Prothesis of the Lower Limb.—This is particularly a prothesis of *strength*, simple or graduated, according to the type of appliance which it is intended to apply. Simple if it is desired to equip persons who perform exhausting work, and who are much more anxious to possess a solid support than an actual artificial limb. As a rule in this case we do not seek to obtain *regularity of gait*. The cripple adopts the " wooden-legged " style of locomotion, the " wooden leg " being either rigid or jointed, and the mode of locomotion not unlike that of a stilt-walker.

The more complicated models are the so-called *artificial legs,* whose design imitates that of the actual limb, in order

to ensure the development of the *step*, in all the phases which compose it. This harmony is inevitably achieved at the cost of solidity, on account of the number of articulations which it necessitates, all along the axis of support.

I shall limit the series of models considered to those which seem to me the best, and which at the present time constitute a portion of the specifications recognised by the military orthopaedists of France.[1]

CXXII.—A. AMPUTATION OF THE THIGH.—(*a*) *The " Pestle " Type with Locking-Joint.*—In the case of patients who have suffered amputation of the thigh, we must first of all consider the old-fashioned " wooden leg," of the " pestle " type, jointed at the knee, but with a locking-joint. This is suited to persons of rural pursuits, and also to all those whose work necessitates much moving about, and causes a certain amount of fatigue. The *rigid* or non-articulated *wooden leg*, which was known even in the days of Pericles, is a makeshift, or, in the words of Paré, " the poor man's leg."

To-day both industrial and social progress condemn the employment of such a wretched and primitive prothesis.

The " pestle " type of leg with the lock, on the other hand, if it is made as it should be, offers notable advantages over its predecessor. It comprises the organ of *attachment*, the *thigh-piece*, the *knee*, and the *leg-piece*.

The organ of attachment consists of an abdominal girdle G, a brace, B, and a sling (Fig. 85). The girdle is of flexible leather, 1·6 inches wide, or it may be of strong ticking, 3·2 inches wide. It buckles in front. It is joined to the thigh-piece by means of a hip-piece H, having almost the shape of a letter T, which is made of steel. The horizontal portion of the hip-piece, riveted and brazed to the vertical portion, is attached by means of two rivets to the belt, which is divided for the purpose. The vertical portion contains two articulations ; firstly a socket-joint *j*, situated about one-sixth of

[1] Since 13 June, 1916. The results of the labours of the Specifications Commission (Commission du Cahier des charges) are assembled in the Prothetic Laboratory of the Conservatoire National des Arts et Métiers.

B

G

T. P.

Outer Face

Section of thigh-piece

Knob

Sling

T.P. P

S   V   S'

C
Cap
Bolt

Bolt

Tractor

Stirrup

Bilateral
Locking-Bolt
(From back)

Parade
leg

Ankle

Wooden Foot

Rubber
Leather
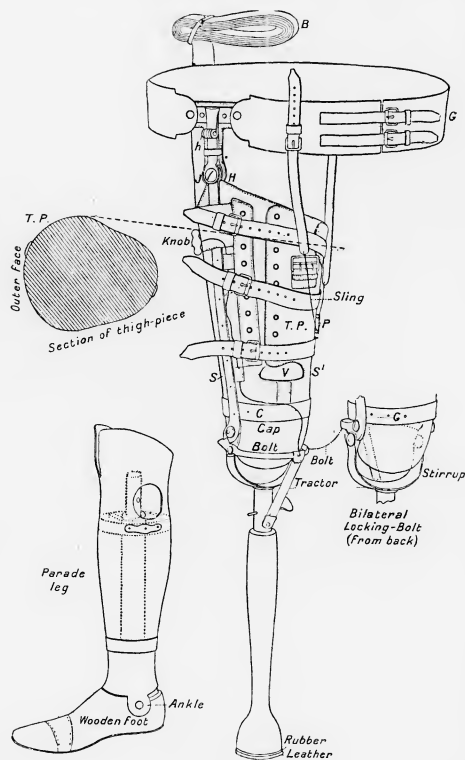
Fig. 85.

an inch behind the anatomical coxo-femoral articulation, working in the antero-posterior plane, which reaches the edge of the great trochanter; secondly, a hinge h, with a check which limits the flexion external to the pelvis to 30°; it is placed *immediately* beneath the horizontal branch. The vertex is ·4 of an inch behind and on a level with the iliac crest.

The hip-piece is lined with leather or ticking, and is padded. It prolongs the external standard, S, of the thigh-piece. Care must be taken that it fits very accurately to the body, whose shape it assumes.

For short stumps the hinge h must be suppressed.

The *brace* is made of strong elastic webbing, one and a half inches wide. Its extremities are riveted, one to the outer surface of the thigh-piece, toward the middle of the body in front, and the other to the side at the back; it buckles in front, after passing over the opposite shoulder; it is kept in place by a second brace which passes over the other shoulder.

Finally, the *sling* consists of a piece of catgut, which passes under a little pulley, P, which is fixed to the inner standard of the thigh-piece; it is attached to the girdle front and back by means of straps and buckles.

CXXIII.—The thigh-piece, T.P., is a conical sheath, of moulded leather, as rigid as possible (density = 1), lined with very tough chamois leather. It presents a comparatively flat surface corresponding to the external and lateral portion of the stump, which ensures a firm attachment (see section).

The whole of the supporting surface is as rigid as possible, and of reduced thickness

The sheath is armed with two steel standards, S and S', about nine-tenths of an inch in width and one-sixth of an inch in thickness. About the region of the knee this thickness is increased to one-fifth of an inch. These standards are parallel with the axis of the femur, outside and inside, and are riveted firmly to the thigh-piece with copper rivets. A circular hoop of mild steel, C, also riveted (an inch and a quarter in width and a twelfth of an inch in thickness), unites

the lower extremities of the standards. The outer standard is pivoted to the hip-piece, as we have seen.

A second hoop, or rather half-hoop, of nickel-plated steel unites the two standards internally toward their upper extremities. One end of it overlaps the internal standard by two inches or so, and then turns downwards. The hoop is therefore complete at the back and open in front. The postero-internal portion is widely splayed, the upper edge being turned outward from the axis of the limb.

The thigh-piece is split in front as far as an opening V which serves as a ventilator, and here the two halves of the sheath are united. There is a sufficient interval left between two rows of eyelet-holes to permit of the progressive tightening of the lace as the stump diminishes in size. The closing of the thigh-piece is completed by means of three straps, sewn and riveted, which buckle toward the side of the outer standard.

The rim of the thigh-piece is scalloped on the postero-internal edge, corresponding to a *concave line of ischial support*. This portion is slightly padded, in order that it may not rub nor inconvenience the opposite thigh. The remainder of the rim is convex in form, bending inwards, and higher at the level of the hip-piece. The thigh, supporting the ischium, is thus gripped on every side, and cannot turn in the thigh-piece.

This latter, finally, terminates in a separate leather cap, stamped or hammered, and seamless, which is riveted to and strengthened by the lower steel hoop, which, like the upper hoop, is nickel-plated.

CXXIV.—The *knee* comprises a stirrup of forged steel, fixed by two screws to the standards, which are curved in such a way as to keep the axis of the articulation two-fifths of an inch to the rear of a vertical line dropped from the coxo-femoral articulation. The articulation of the knee consists of two butt-hinges, giving a flexion of 90°. They are contrived in two flattened shoulder-pieces which form the lower extremities of the standards. The form of the stirrup

is that of a deep curve (parabolic); its thickness is one-fifth of an inch, and its greatest width one and a half inches.

The pivot of each articulation is riveted on the inner face of the stirrup; the shoulder-pieces are bored, and free at the extremities; the faces of the shoulders meet in a plane which passes through the axis of the bearings, making an angle of 60° with the horizontal.

The stirrup clears the cap of the thigh-piece by three-fifths of an inch at the centre. At its base is affixed perpendicularly, on a vertical axis, by means of two tenons diametrically opposed, a hollow steel tube in which the shank is fixed. The tenons are riveted into mortices cut in the thickness of the stirrup, and the joint is then brazed. A flat forged in the stirrup facilitates the adjustment of the two portions without reducing the thickness of the metal.

The knee also comprises a *bilateral locking-bolt,* an arc of steel whose extremities are fixed by screws to the outer sides of the two standards of the thigh-piece. It may lie in front or behind the latter indifferently. It bears a spur at either extremity, lying in the plane of each articulation of the stirrup. It lies as close to the thigh-piece as possible.

The spur must be so contrived as to engage accurately in the angle formed by the shoulder-piece of the standard. The bolt is alike at both ends; its section is oval, except at the extremities, which are flat, and one-fifth of an inch in thickness. A powerful elastic tractor is attached to the bilateral bolt at the summit of the arc, and also to the steel tube of the shank. It serves to send the bolt home when it is intended to lock the articulation of the knee. But to allow of flexion the bolt is raised by means of a string of catgut, one end of which is fixed to the centre of the arc, while the other runs through an eyelet riveted to the upper portion of the thigh-piece. It is attached to a small knob or handle, which is pulled to disengage the bolt.

CXXV.—The *shank* is made of ash, in preference to any other wood, and is cylindro-conical; its diameter varies from 1·3 inches to 1·7 inches. The tip is enlarged to 2·8 inches,

and a sole of leather is affixed to it with nails. The lower surface of the " shoe " is convex, with a radius of 3·6 inches. Between the leather and the wood is a circular piece of sheet rubber, one-tenth of an inch in thickness.

The shank is fixed to the thigh-piece by means of a hollow tube brazed to the stirrup. The upper end of the shank is shod with a tube of steel fixed by means of screws ; a gentle pressure should suffice to make it enter the sleeve of the stirrup. A small hole is drilled through the shank, and a boss is brazed to the external sleeve, boss and shank being drilled and tapped. The shank is fixed by means of a thumb-screw. For country work the shank should have a shoe 4·8 inches in diameter, fashioned precisely like the smaller shoe. If the weather is damp or the soil moist the sole should be greased, in order to avoid such a phenomenon of suction as is produced, for instance, by a school-boy's wash-leather " sucker." The objection to wooden shanks is their fragility ; they expose the wearer to accidents ; a hollow tube of *duralumin* might be substituted, the wooden shoe being screwed into the lower end of it ; or shanks of hollow wood may be employed, of a larger diameter.

This type of " wooden leg " should never exceed a total weight of 5·4 lbs.

Returning to the principles of scientific prothesis, we find that the appliances of the " pestle " type possess a small inertia, afford great security of support, and cause a minimum of fatigue while walking. From this latter point of view it is more painful to throw the leg out sideways in walking, as is necessary if the shank is too long, than to limp slightly with a shank of insufficient length.

Let us add that certain orthopaedists occasionally replace the round " shoe " by an actual " wooden foot," articulated in the fore-part. This is physiologically incorrect.

Fig. 86 shows a bad pattern of " parade " leg, with a leather legging. It is fixed by means of an interior shank to the stirrup, the cylindrical shank having first been removed. The correct form of " parade " or " show " leg (Fig. 85) is articulated at the ankle.

The " wooden leg " of the type described can easily be affixed to any thigh stump in which the bony lever projects

Fig. 86.—Legs of the " Pestle " Type.—No. 1 Model with Locking-joint, and defective " Parade " Leg. On the right a real " Wooden Leg."

more than two inches beyond the inguinal crease in the case of very high amputations. Where the lever projects less than

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more than two inches beyond the inguinal crease in the case of very high amputations. Where the lever projects less than

two inches beyond the inguinal crease, or in cases of disarticulation, the arrangement shown in Fig. 87 will be adopted.

There are three types of the "wooden leg" with the bolt or knee-lock; Nos. 1, 2 and 3, the two latter characterised by a wide moulded girdle, while No. 3 possesses a double-action bolt B and a guide-rail R, with a thigh-piece the back of which consists of flexible leather.

CXXVI.—(b). The "Artificial Leg."—But it is the "artificial leg" which is principally used by the majority of artisans, clerks, members of the liberal professions, etc.; in a word, by all those who have to consider appearances and the fashion. The artificial leg, furnished with an articulated foot, restores locomotion (as far as walking goes) to a degree which is *almost normal*, and entirely normal if the leg has been amputated some distance below the knee, and if there is no anchylosis of this important articulation.

FIG. 87.—Wooden Leg with Locking-joint No. 3, for cases of Disarticulation of the Hip-joint.

We must briefly recall the *experimental data* of walking[1]

[1] For further details see *Le Moteur Humain*, pp. 440-468.

FIG. 88.—Chrono-photographic Phases of Walking.

in order to throw a light on the entire problem of the prothesis of the legs.

The phases of the step are explained by Fig. 88; the

T

two inches beyond the inguinal crease, or in cases of disarticulation, the arrangement shown in Fig. 87 will be adopted.

There are three types of the "wooden leg" with the bolt or knee-lock; Nos. 1, 2 and 3, the two latter characterised by a wide moulded girdle, while No. 3 possesses a double-action bolt B and a guide-rail R, with a thigh-piece the back of which consists of flexible leather.

Fig. 87.—Wooden Leg with Locking-joint No. 3, for cases of Disarticulation of the Hip-joint.

CXXVI.— (b). *The "Artificial Leg."*—But it is the "artificial leg" which is principally used by the majority of artisans, clerks, members of the liberal professions, etc.; in a word, by all those who have to consider appearances and the fashion. The artificial leg, furnished with an articulated foot, restores locomotion (as far as walking goes) to a degree which is *almost normal*, and entirely normal if the leg has been amputated some distance below the knee, and if there is no anchylosis of this important articulation.

We must briefly recall the *experimental data* of walking[1]

[1] For further details see *Le Moteur Humain*, pp. 440-468.

Fig. 88. Chrono-photographic Phases of Walking.

in order to throw a light on the entire problem of the prothesis of the legs.

The phases of the step are explained by Fig. 88; the

T

supporting leg forms with the foot an angle of 90°, which may be increased by 20° or 25°, but rarely diminishes. The *tibio-tarsal* articulation of an artificial leg should therefore allow of an average excursion of 20° beyond the right angle, but not more than this. It is, on the other hand, if we are facing the subject, behind the articulation of the knee, and this latter is two-fifths of an inch behind the coxo-femoral articulation; the thigh, therefore, has an oblique antero-posterior inclination, and the line of gravity of the body passes through a point in advance of the tibio-tarsal articulation, preventing the *bending of the knees*. The contraction of the quadriceps produces the same effect. We must therefore give the hinge of the knee-joint sufficient play to allow of walking on the level, ascending a staircase, or sitting down, but must endeavour to avoid the tendency to sudden flexions, which would result in falls. The walk must not be a series of oscillations of the artificial limb caused by the periodic impulsions of the stump. We know also that the thigh and the lower leg form a less angle than 180°, and that during the phase of impulsion the rear lower leg leaves the ground flexed at an angle of about 160°.

Finally, I will add this important detail, that the foot should be turned 15° *outwards*, and that its *inner edge* should be slightly raised. In this way a defective gait will be avoided, as also lateral oscillations of the body.

Many types of artificial leg, constructed of wood and leather, have sought to reproduce this or that physiological element of the gait. None of these are *perfectly rational*.

The *American models*, perfected during the years which followed the War of Secession (1860-1865), have often appeared to possess great advantages. In reality these appliances are copies of one another, and remain faithful to uniform rules of construction which are far from satisfactory. The *foot is too heavy*, and its excursion badly calculated; the knee, too loose, betrays the considerable inertia of the lower leg by means of jerks; the lower leg itself, accordingly, is subject to sudden oscillations, which have to be corrected by the impulses of the other leg; otherwise the *necessary extension*

of the limb in its phase of vertical support will not be obtained. Above all, the *articulations are not in their right places*; so that the wearer runs the risk of an occasional accidental flexion of the knee: that is, of a fall.

These faults are in themselves sufficiently serious: I need not therefore insist on the *insufficient attachment* of the organs by means of simple braces; the incorrect formation of the thigh-pieces, which do not closely embrace the supporting surfaces of the stump; the resonance of wood, which makes a sounding-box of the appliance, and its fragility.

In the victims of amputation who have worn artificial limbs of the American type, and have covered a mile or more at their own pace, I have noted a defective, often dangerous, and always fatiguing gait. Nevertheless, there are some American models which appear to me to be highly satisfactory.

CXXVII. Expert Examination of an Artificial or " Wooden " Leg.—The method of observation to be applied to prothetic appliances of the lower limb is two-fold. On the one hand I register, on my *dynamographic gangway*,[1] all the phases of support and propulsion, the locomotive efforts, and the duration of the elements of activity of the two legs, the normal and the artificial (Fig. 89). On the other hand, I measure, by means of the respiration gauge (p. 74), the expenditure of energy involved by walking 1 kilometre with the model under examination.

We may state simply that the *gangway* records, for *each* of the two lower limbs, *four kinds of forces*: the supporting pressure, the backward impulse, and the lateral thrusts, outward and inward, as shown in Fig. 90. The apparatus consists of levers resting on springs of calculated strength, which are in contact with small rubber bulbs. The graphs obtained (Fig. 91) show that peasants naturally walk with a gait rather similar to that of the artificial limb; they throw the feet outwards a little, and the backward impulsion is negligent. Every defect in locomotion which can be imputed to the model under examination is clearly revealed in the trac-

[1] *C. R. Acad. Sc.*, 31 July, 1916, Vol. CLXIII., p. 130.

FIG. 89.—Testing an Artificial Limb on the Dynamographic Gangway.

ings. In particular, if the cripple leans much less heavily on it than on his sound leg, the appliance is badly designed or fitted, or there is some cause of pain, or fatigue merely.

Rest   Gangway   Right   Left

Joint   Supporting lever

Socket   Universal lever   B   Section

Elevation   Stretcher
B.B. Bulbs   S.S. Springs
Dynamographic Gangway.

FIG. 90.

Analysis of Gait

3   Vertical Pressure   2   Rigid
"Pestle"   7

Backward Impulse   Amputation of
lower leg
(Middle)

Inward Thrust   (Daviaud)

Outward Thrust
Vibaille   Pluchot   Left
(Peasant·Normal)   (Normal)

Time in fifths of a second.

Vertical Pressure

Backward Impulse   Right

Inward Thrust

Outward Thrust
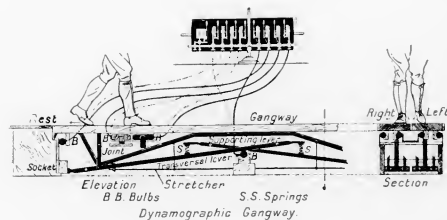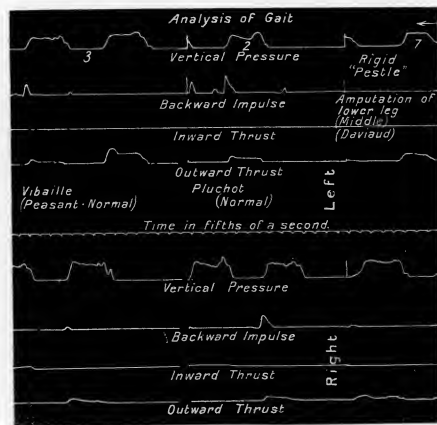
FIG. 91.—Tracings of Footsteps made with the Dynamographic Gangway.

FIG. 89.—Testing an Artificial Limb on the Dynamographic Gangway.

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FIG. 90.
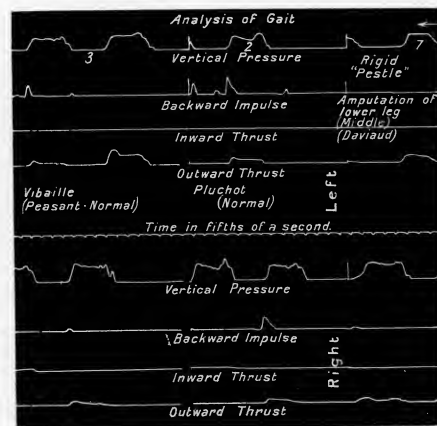
FIG. 91.—Tracings of Footsteps made with the Dynamographic Gangway.

We may thus pronounce, without fear of error, on the comparative value of the different models, and on the progress accomplished in their manufacture.

A faithful, precise, and impartial analysis is obtained, which will prove a reliable guide to the technique of orthopaedics, and will fertilise the mind of the inventor.

The gangway is also employed in order to watch the effects of the functional re-education of the limbs ; it corrects the process, and accelerates it.

CXXVIII. **A Model Appliance for a Case of Femoral Amputation.**—I will here describe the type of artificial leg (Fig. 92, to the left) which is at present the best. Let us begin with the *thigh-piece*. This is precisely like the thigh-piece of the type already described, with its organs of attachment, girdle and hip-piece, and brace with double buckles ; its organs of consolidation are two lateral standards and two metallic hoops. The knee contains two hinged articulations contrived, in a line with the transverse axis, in the standards of the thigh-piece and the lower leg. They are countersunk, with a check which limits their play to an angle of 85° of flexion. The external check forms a portion of the metallic standard of the lower leg ; it is fixed upon the other by means of a pivot and lock-nut.

When the appliance is in use the articular centre of the knee should be $\frac{2}{5}$ of an inch behind the line of the coxo-femoral articulation. The standards are elbowed to give this result. The thigh-piece is modified in the lower portion ; the leather cap is pierced by a slit running in an antero-posterior direction, in order to allow an elastic tractor, T, to pass through it. The object of the latter is to oppose a greater or less resistance to the flexion of the knee. It is therefore made adjustable at will. For purposes of adjustment a catgut string is attached to the interior, in front, at the base of the standards of the thigh-piece ; it extends at least $1\frac{1}{5}$ inches beyond the total height of the cap, and is attached to a spiral spring of steel, of appropriate strength. A strap of tough, flexible leather, pierced with eyeletted holes, completes the attach-

ments of the tractor. It passes through a little window contrived at the base of the calf, in a prolongation of the

For Cases of Amputation of Thigh.   For a Case of Amputation of the lower Leg (short stump).

FIG. 92.—Artificial Legs in Leather.

malleolar circle, and makes it possible to regulate the tension by hooking this or that eyelet on the stud on the forepart of the limb.

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For Cases of Amputation of Thigh.

For a Case of Amputation of the lower Leg (short stump).
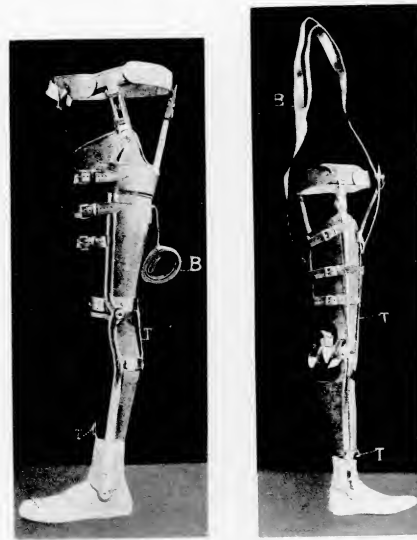
Fig. 92.—Artificial Legs in Leather.

malleolar circle, and makes it possible to regulate the tension by hooking this or that eyelet on the stud on the forepart of the limb.

The elastic equilibrium of the knee is completed by a tractor T, which acts upon the posterior face, being firmly riveted to two attachments, on the lower portion of the thigh and the upper portion of the calf.

Finally, to prevent the leather from " giving," the slit in the cap, and the upper edge of the calf, are bound with a strip of steel which keeps the material strictly in shape. It is riveted with small copper rivets.

The lower leg or " gaiter " is a sheath of moulded leather, approaching as closely as possible to the shape and size of the sound lower leg. Two lateral standards, about $\frac{11}{16}$ of an inch in width, riveted to the leather, ensure rigidity. They terminate at the upper extremities in the articulations of the knee, while at their lower extremities they are drilled to receive the axis of the malleolar articulation. A semicircle of steel, placed behind and a little below the knee, strengthens the standards and the leather sheath. The foot is wholly of wood, or the fore part F may be of felt, glued upon the malleolar portion. In either case there will be a " wooden ankle," with socket articulation : the shank-piece furnishes the socket or mortise, and the foot the tenon.

A steel axis, covered with leather, traverses the whole joint and the lower extremities of the standards ; it is inclined from front to back and from inside to outside, in order to throw the foot outwards, so that it makes an angle of 15° with the antero-posterior line.

The angle which the lower leg makes with the foot is one of 90°, which may be increased to 110° only. These limits are assigned by the uniform and elastic action of a " double-action " spring, made of steel wire one-sixth of an inch in diameter. The felt toe-piece gives lightness, and also a flexibility which may dispense with an anterior articulation.

Fig. 93 shows, beside the type which has been described, the average weight of which is 7¼ lbs., models constructed of wood, either of French or American make. The foot possesses two articulations ; the cheeks or abutments are padded with rubber. The appliance worn by the cripple is the most interesting. This French model is characterised by the

ingenious articulation of the knee. Here we see a checkpiece, C, with two elbows, formed of a piece of steel which is pivoted on an internal axis situated at the base of the

Fig. 93.—Models of artificial Legs in Wood (the two central Models) and Leather (left and right).

thigh-piece, the free end of which abuts upon the posterior surface, of the lower leg (Fig. 94). It rests in contact with this surface owing to the action of the tractor T. This

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Fig. 93 shows, beside the type which has been described, the average weight of which is $7\frac{1}{4}$ lbs., models constructed of wood, either of French or American make. The foot possesses two articulations; the cheeks or abutments are padded with rubber. The appliance worn by the cripple is the most interesting. This French model is characterised by the

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mechanism fulfils a double function ; it limits the forward play of the thigh upon the lower leg to an angle of 180° ; and it *automatically* rights the lower leg in case of a flexion greater than 90° ; which prevents all possibility of a fall.

Fig. 94.

When the flexion exceeds 90°, as when the wearer sits down, for example, the tractor ceases to act. This result, it is plain, depends on the position of the pivot of the check-piece, and may be calculated exactly.

The whole appliance, for an amputation of the thigh, weighs 6½ lbs., and allows of a very comfortable gait.

Nevertheless, in the case of amputations of the thigh the orthopaedists should aim at the construction of artificial legs weighing not more than 2 kilogrammes (4 lb. 7 oz.). The uses of *multiple-ply wood*, or *duralumin* should make such a result possible without impairing the strength of the appliance.

CXXIX.—B. AMPUTATIONS OF THE LOWER LEG.—Any stump exceeding 2·8 inches in length is fitted with an appliance of the *tibial leg* pattern ; the particular model being No. 1 (Fig. 95), No. 2, or No. 3, according to the length of the stump, the last being intended for cases of the so-called *tibio-tarsal* amputation, in which only the foot is removed (Fig. 96). In all these cases a sufficient " scallop " or " window " must be contrived at the back of the knee. The " gaiter " or leg-piece is of moulded leather, which must be extremely rigid ; it is lined with tough chamois-leather. The upper edge is padded in front ; this serves to support the weight of the body ; it is the *principal support*. To this support we must add the pressure uniformly distributed all over the stump ; it moulds itself, accordingly, on the sub-condylar tables of the tibia.

Fig. 95.—Tibial Model No. 1.

Fig. 96.   Tibial Model No. 3, for tibio-tarsal Amputation.
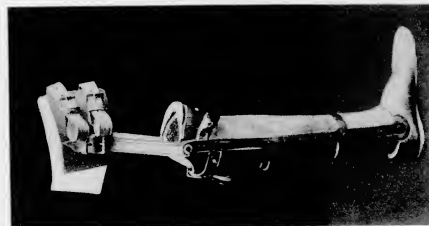
Tibial Model No. 2.

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The whole appliance, for an amputation of the thigh, weighs 6½ lbs., and allows of a very comfortable gait.

Nevertheless, in the case of amputations of the thigh the orthopaedists should aim at the construction of artificial legs weighing not more than 2 kilogrammes (1 lb. 7 oz.). The uses of *multiple-ply wood*, or *duralumin* should make such a result possible without impairing the strength of the appliance.

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FIG. 95.   Tibial Model No. 1.

FIG. 96.   Tibial Model No. 3, for (tibio-tarso) Amputation.

Tibial Model No. 2.

It is here that a correct moulding should be the aim of the maker. The anatomical application of the appliance demands very careful attention. The support will be chiefly lateral, the weight bearing on the outer surface of the lower leg; if it were on the inner face it would be productive of pain.

The same applies to Chopart's amputation,[1] which enables the subject to stand upon the stump; but the two bearing surfaces are so adapted as to intervene simultaneously.

If the stump of the lower leg is less than 2·8 inches in length it will be flexed, so that the cripple will " walk on his knee " (see Fig. 92).

CXXX.—C. DOUBLE AMPUTATIONS.— In cases of amputation of both the lower limbs the appliances will be designed according to the foregoing indications. However, subjects who have suffered amputation of *both thighs* will be provided *exclusively* with legs of the " pestle " type, with locking joints, well and strongly constructed, the normal length of the shank being reduced by 2 to 4 inches, according to the case. There must be no sacrifices for the sake of appearances; such would be criminal. Thigh-stumps which can be fitted with artificial legs with free joints are extremely rare.

CXXXI. **Prothesis of the Upper Limb.**—This prothesis is more difficult than that of the lower limb. For a long time it was neglected; not long ago it seemed to be given up in despair, and the experts in particular laughed at the idea of making a one-armed man work. The early attempts, by Laurent (in the fifteenth century), whose name is recorded by Paré, by Father Sebastién in the eighteenth century, and by the Comte de Beaufort in the nineteenth century, were by no means encouraging. Hugedé, in 1873, had no better success with his model arm.

We therefore applied ourselves to the subject, and after a thorough study of it we discovered that it presented no insurmountable difficulty from the technical and mechanical point of view.

[1] An amputation which leaves only the heel and the astragalus or ankle-bone.

By means of an *experimental arm* (Fig. 97), with a spherical joint, which could be locked at will, to replace the wrist, with a steel rod for the fore-arm, and a means of attachment to the thorax, all the portions being capable of modification and adjustable at will, we were able to devise and construct a *true artificial arm, capable of performing hard manual labour; simple, strong, and practical.*[1]

FIG. 97.—Working Arm being tested, with various prehensile Attachments for holding Tools.

On the other hand, a skilful orthopaedist, M. Cauet, undertook, under our direction, investigations which enabled us to construct a *mechanical arm, entirely automatic in its control*, which is suitable for those following the " liberal professions."

These two models, the worker's arm and the mechanical arm, may be adapted to all amputations of the upper limb. They offer the advantage that they are quickly constructed,

[1] *Journal de Physiologie*, p. 860, 1915.

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according to a type which is, so to speak, standardised, so that these models can be repeated with slight variations.[1]

CXXXII.—A. AMPUTATION OF THE UPPER ARM.—(a) *Worker's Arm* (Amar).—The model known as *Amar's worker's arm* (*bras de travail Amar*) is adaptable to all amputations leaving a stump more than two inches in length, measuring from the line of the armpit. It comprises : the attachment ; the brachial sheath ; the metallic fore-arm ; universal holder ; universal ring ; hook ; and parade or "show" hand.

The *attachment* consists of a scapular portion and a thoracic portion (Fig. 98).

The *scapular portion* consists of a plaque of leather, moulded to shape, and lined with fine tough lambskin or chamois leather. It should descend as far as the horizontal line drawn through the armpit, and should cover the shoulder for a width of 3·6 to 4 inches, coming into contact with the acromial arch without overlapping it. The *thoracic portion* is intended to hold the former firmly in position. It is a girdle of leather, of flexible calf-skin, or of inelastic fabric, 1·6 inches in width ; it is fixed at its two extremities, by means of tubular rivets, to the shoulder-piece. It encircles the thorax, passing under the opposite armpit, where it is covered with a moveable sleeve of lambskin or chamois, padded, and eight inches in length. In its dorsal portion the girdle contains a segment of strong elastic webbing, 2·4 inches in length. In front it is fastened by means of a nickel-plated buckle (preferably without a tongue).

The *brachial sheath* is of moulded leather, as rigid as possible, and lined with soft leather ; it is split down the front, the edges revealing a wide strip or tongue of thin flexible calfskin. The closing is assured by sewn and riveted straps and small buckles. It possesses a metallic reinforcement consisting of a dome of steel $\frac{1}{11}$ inches in thickness, which is prolonged by two standards, situated on the outer and the inner side respectively, the whole being forged in one piece. The standards are riveted firmly to the leather (with copper rivets).

[1] Jules Amar, *C.R. Acad. Sc.*, 13 March, 1916, Vol. CLXII., p. 401.

The dome possesses a central core of steel, which is brazed on ; it is bored for a tap of *international pitch* (10 mm. and 1·5 mm.).
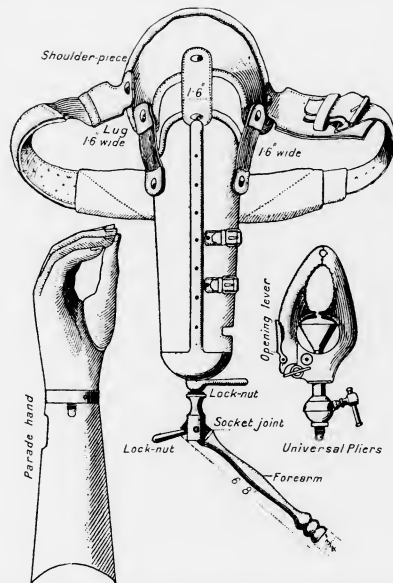
FIG. 98.—Amar's Worker's Arm with Parade Hand and universal Grip or Pliers.

The outer rim of the sheath is convex (the radius of the curve being of some length) and projects upwards ; the inner rim is slightly hollowed at the armpit.

The articulation of the sheath at the shoulder consists of three straps or lugs, fastened by tubular rivets ; an acromial strap of flexible leather, which supports the whole apparatus ; a dorsal strap, longer, and of strong elastic webbing, giving an elongation of 1·6 inches ; and an anterior strap of flexible leather, or even of elastic webbing.

The total length of the brachial appliance will be less than that of the sound arm, to permit of the attachment of a piece of steel jointed to the fore-arm ; unless a *disarticulation of the elbow* is in question.

CXXXIII.—The *metallic fore-arm* consists of a rod of steel weighing about 6½ ounces ; its form guarantees great strength with a small mass.

It is provided with a socket joint cut in a cylindrical piece of steel which screws into the tapped hole in the dome. This joint is controlled by a small lever on the outer side of the arm. A lock-nut makes it possible to place the stem in any plane, while the joint of the elbow allows of angles of flexion varying from 180° to 45°. The free extremity of the fore-arm is bored and tapped with a thread of the pitch already mentioned, in order that it may receive the following appliances ; the *universal holder*, the *universal ring*, the *hook*, and the *parade hand*.

The holder is of bronze or forged steel ; it is shaped like a lobster's claw. Its characteristics are : *a ball-and-socket joint*, enabling it to be turned in all directions, and fixed in any given position by means of a small locking-screw and lever ; and an *eccentric*, to ensure the firm closing of the jaws, which open by means of an *automatic control*, actuated by a small lever which is afterwards pressed downwards (see Fig. 98). The tips of the jaws make it possible to seize a tool or any other object ; tools fitted with a handle are thrust into a special funnel-shaped holder, where they remain firmly fixed.

The *universal holder* suffices the worker for the great majority of purposes ; but the *universal ring* may also be used (see A, Fig. 99). This comprises a steel head, part of which forms a screw (international pitch) ; it is drilled in two directions, the axis of the holes being at right angles, so that one hole opens

υ

into the other. In one of these holes is placed the shank of the ring, which is fixed by means of a locking-screw with lever handle working in the other hole. This shank is shaped with a grooved neck, so that it may be turned freely without falling out. The hook, B, is sufficiently explained by the figure ; it is fitted into the same head as the ring. Grip, ring, and hook are nickel-plated.

Finally, the " parade hand " is made of wood (lime) ; it is well shaped, resembling the sound hand as closely as possible ; the fingers are half-flexed and rigid ; they are split along their length from front to back, and a thin slip of wood with the fibres running longitudinally is inserted, in order to increase their strength. The thumb is jointed, and opposed to the index and middle fingers. The tips of the thumb and the first two fingers are counter-sunk and provided with rubber pads. In the centre of the wrist is fixed a threaded shank, the pitch of the thread being as before mentioned, so that it

Fig. 99.

may be affixed to the fore-arm. By means of a nickel-plated band, which is screwed on, the lower portion of a rigid leather sheath is attached to the wrist. This envelopes the fore-arm as far as the elbow, where the edge is hollowed out to permit of access to the locking-nut. A small opening at the base of the sheath gives access to the locking-screw at the extremity of the fore-arm.

All the threaded portions should be made with an *easy entry*, corresponding to three threads, in order to obviate fumbling and economise the wearer's time.

CXXXIV.—(*b*) *Amputations very near the Shoulder, and Disarticulation of the Shoulder.*—If the stump to be fitted is
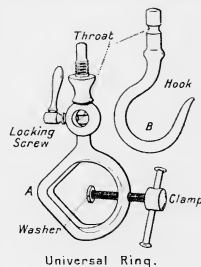
less than two inches in length, measuring from the line of the armpit, or if the upper arm has been disarticulated, the procedure will be as follows :

In the first case, the model should be the *parade arm*, *No.* 1. With this it is still possible to utilise, though only to a very slight extent, the small moveable stump of the arm, and the muscular power of the shoulder.
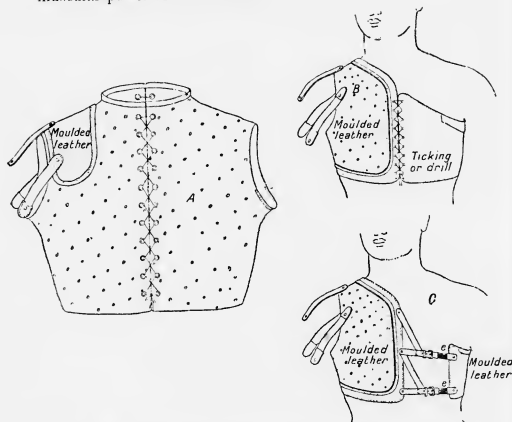
Fig. 100.—Waistcoats for Amputations, leaving a short Stump or none.

This type of arm is characterised by its organ of attachment, which consists of a waistcoat of strong perforated fabric, with celluloid eyelet-holes, perfectly fitting the thoracic cage. It is laced back and front. On one side is a shoulder-piece of flexible leather, to support the appliance ; a counter-support of padded leather passes under the opposite armpit. The waistcoat will not be cut too low, or it will allow too much play (Fig. 100, A).

The waistcoat may, according to circumstances, assume different forms. Half may be made of leather moulded to the thorax and the shoulder involved ; it should be lined with lambskin or chamois. Numerous ventilation holes are pierced through the leather ; and a metallic reinforcement, formed of a strip of steel two-thirds of an inch in width, should be affixed to the edge, on the outside. The other half of the waistcoat may be of very strong *ticking*, with padding under the armpit (B).

A last type of arrangement may be left to the choice of the patient. It consists in joining the semi-corset of perforated leather to a wide counter-support of padded leather placed under the opposite armpit. The two portions are connected by straps arranged as in C, riveted at their extremities, and containing an elastic insertion (*e*, *e*). This arrangement is, in my opinion, the best.

The brachial sheath is entirely closed : it reaches the crest of the acromion on the one side, and the armpit on the other, and is held in this position by the three links already described as supporting the worker's arm. But these will be short, in order that they may not allow the appliance too much play. Lastly, the shank of the fore-arm will be of reduced dimensions, except as regards its length. The attachment will be modified if the shoulder is anchylosed ; it will form part of the brachial sheath, but will be perfectly moulded, covering the middle part of the clavicle and the spine of the scapula, and will be cut away at the armpit.

In the second case, *when the shoulder is disarticulated*, the type of arm fitted will be parade arm No. 2, whose characteristic feature is that the waistcoat is replaced by a semi-corselet of moulded leather, reinforced by strips of steel, as in B (Fig. 100). The remainder of the corselet is made according to the pattern of the semi-corselet of ticking or the strapped waistcoat. The leather is moulded into a cap simulating the shoulder ; and this cap must be very strong, being reinforced with steel bands if need be, in order to protect the stump. The arm is attached by means of a detachable hinge, which is closed by a reversible clutch, or by a key. A large indentation,

edged with a ribbon of steel riveted to the leather, enables the arm to be affixed to the shoulder-cap. The external standard of the brachial sheath is therefore prolonged to join the acromial band of steel, being articulated in a
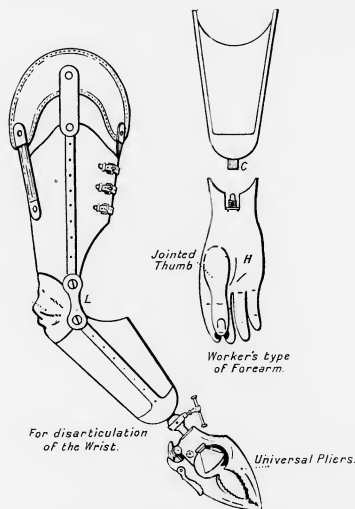
Fig. 101.—Worker's Type of Fore-arm (Amar).

line with the transverse axis of the shoulder-cap. A screw and nut limit the oscillations of the arm to 45° in front of the body and 20° to the rear; which is sufficient for appearances.

As for the hinge, it is situated at the peak of the acromion,

and its full excursion raises the arm to an angle of 90°; it should be given a width of ·8 inches to 1 inch. The wearer can then withdraw the arm at will, while his shoulder is protected against the possibility of shock.

CXXXV.—B. Amputation of the Fore-arm.—There are two cases to be considered, according to the length of the stump.

(a) *Cases where the Stump measures more than* 2·6 *inches from the internal Crease of the Elbow.*—The model will include the *worker's type of forearm*, in which the brachial sheath is largely cut away in the neighbourhood of the elbow (Fig. 101) : its standards will accurately follow the slight bi-concavity of the upper arm. At the extremities of these standards, and those of the sheath of the fore-arm, two thongs of flexible leather, T, shaped like a figure 8, are fixed by means of steel screw-bolts and nuts. These thongs are made long and narrow, so as to permit of the full degree of pronation and supination of which the stump is capable. An elbow-guard of dogskin or other tough material covers the elbow, and is sewn to the posterior and opposing edges of the two sheaths, leaving play for a flexion of 50°. The sheath of the fore-arm is made a tight fit, and is closed for short stumps ; for longer stumps it is laced or buckled on the anterior face.

Cut away at the elbow, it should allow of the full degree of flexion possible to the stump.

It terminates in a dome and a shank of steel, provided the length of the latter is not less than 3·2 inches, in which case the sheath will be continued to the wrist. In a case of *disarticulation of the wrist* the central core C of the dome will be brazed to the outside instead of to the inside of the latter. This must be taken into account in making the parade hand H, which must be hollowed at the wrist in order to receive the screw attached to the dome.

The principle of all these arrangements is to keep the dome in contact with the stump, in order that the sensibility of the latter may be utilised to obtain an increased dexterity of movement.

CXXXVI.—(b) *Cases where the Stump of the Fore-arm is from* 1·6 *to* 2·4 *inches in length.*—Short stumps of the fore-arm are usually a great obstacle to prothesis. The following arrangement, known as the *lever fore-arm,* solves the difficulty. The standards of the *brachial sheath* are strengthened at the
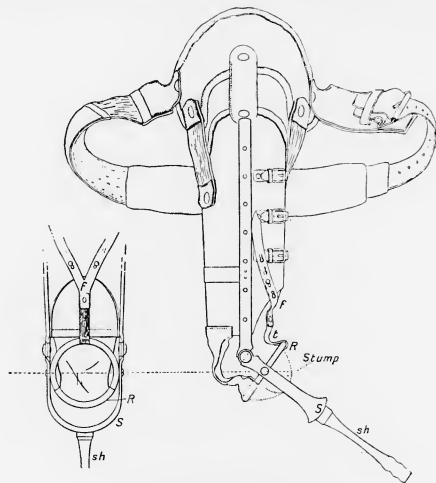
Fig. 102.—Lever Fore-arm (Amar).

lower ends, and form a hinge with the two arms of the stirrup (Fig. 102, S). The axis of the double hinge is strictly in line with the transverse axis of the elbow-joint, which is inclined from without inwards, and from above downwards, at an angle of about 10°. It is essential to allow for this inclination. An iron ring R (made of ¼ inch rod iron) surrounds the stump at

a distance of 1·2 inches from the crease of the elbow. It is made to rotate upon one of its diameters. The posterior arc of the ring is covered with dogskin, which is sewn to the ring on the one hand and the brachial sheath on the other. This must be of such dimensions as to allow the stump to describe its greatest degree of flexion. A strong elastic tractor attached to the anterior portion of the ring is affixed to the brachial sheath by means of a forked strap. This brings the ring back to its first position, and prevents the stump from escaping.

On the axis of the elbow-joint is mounted the stirrup, the arc of which affords a maximum of strength; the stump controls it by means of the ring, communicating to it all the flexion and extension possible. It is forged in one piece, of wrought steel, being at least half an inch wide and one-tenth of an inch thick. The articulations permit of a flexion of 75°, being countersunk hinges mounted with bolts and nuts.

In the centre of the arc of the stirrup is a brazed attachment, bored and tapped with a thread of international pitch, to receive the shank of the fore-arm S, which is *only* 4 *inches in length,* and in thickness is equal to that of the parade arm.

All the models which have been described are perfectly practical and of proved strength. They are so well adapted to professional needs that during two years' experience of their use no modification has appeared desirable.

CXXXVII. **Various Appliances.**—Before examining the *Cauet type* of mechanical arm, which is intended more particularly for the " liberal " professions, we must mention certain appliances which seem to offer certain advantages to the working-man.

In France inventors have been inspired by the type fitted with the *universal holder* or *pliers.* A model has been recommended which is equipped with a *universal joint,* which is certainly extremely mobile, but is unsuitable for the exertion of any great effort. It does not present any real improvement over the simple universal ring, the grooved throat of which gives just the mobility desired in appliances required for purposes of manual labour, and also for the exertion of force.

The *pliers with universal joint* is a specialised organ : now it is by no means the object of prothesis to produce such, but, on the contrary, to reduce the number of *special* working appliances to a minimum.

Many other inventors have fallen into this error, who, after considering this or that professional operation, have set themselves to devise—and not without success—a series of adequate *instruments*. The same cripple would be obliged, under these conditions, to mount upon his artificial limb now a file-holder, now a chisel-holder, etc. ; involving a waste of time, and implying a faulty adaptation of the stump ; inconveniences which it is important to avoid in the case of wounded men seeking employment.

It is moreover recognised that although the execution of certain movements is correct when one of the specialised attachments is employed, others are distorted, owing to a lack of synergy arising from this very specialisation.

Nor must we seek to transform the artificial arm into an *agent of support*, thereby complicating its function. The example of the *magnetic hand* is, in this connection, one of the most enlightening. The magnetic hand[1] consists of an actual electro-magnet, the form of which varies according to the tool to be held (pincers, pliers, chisel, file). In the case of the file the electro-magnet assumes the aspect of a pot, attached by a sleeve to the fore-arm, a ball-and-socket joint being interposed (Fig. 103). The coils receive the current from a portable electric battery, or the factory circuit ; contact is made or broken by the other hand or the foot.

It may readily be imagined that such an arrangement is cumbersome, despite its appearance of flexibility ; we must also take into account the magnetic inertia of the appliance, the fumbling to get the magnet in the right position, the necessity of providing every tool with an iron armature, and the difficulty experienced by the wearer in co-ordinating his movements with the making and breaking of the current. We may also mention that the cost of the current consumed must be a considerable expense to the manufacturer.

[1] *The Electrical Review,* 14 January, 1916.

In Germany, it would seem, the tendency is toward a simple and universal prothesis, similar to that whose principles I have been defending. The objects pursued have been convenience of work and its low cost. Such, in my opinion, is the true doctrine.

CXXXVIII. **Mechanical Arms.**—Mechanical arms are intended to realise *automatic* movement ; and in particular to
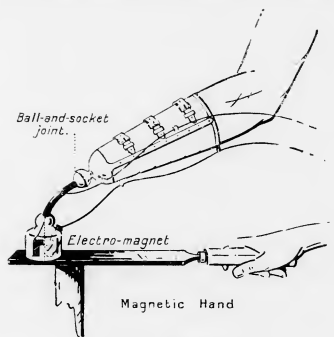
Fig. 103.—Magnetic Hand.

afford *mobility of the fingers*. These are therefore *articulated*. We have an example of such articulation in the jointed thumb of the parade hand, which is sometimes controlled by a cord actuated by the shoulder of the opposite side. The best models of mechanical arms are those of the Cauet type. I have for a long time been seeking to improve this type of arm. To-day it is certainly the best.

The essential organ of these appliances is the *hand*, which is *articulated*, and is made of *metal*, with the exception of the tips of the fingers, which are covered with cork, rubber, or felt, in order to lessen shocks and improve their holding power.

The play of the articulations is assured by the movement of a *breast-band* which encircles the thorax, or of braces applied to the shoulders; these movements are transmitted to the hand or fore-arm by steel cables (Bowden wires).
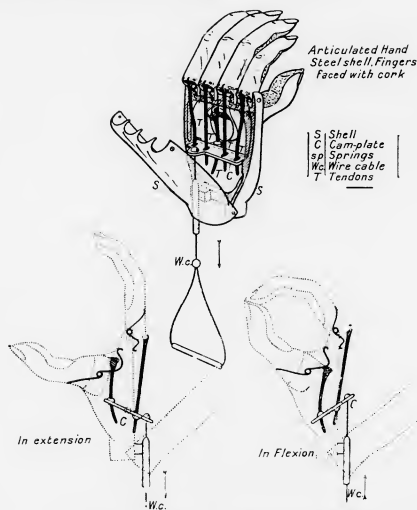
Fig. 104.—Articulated Hand (Cauet Type, Amar's Model).

Let us now consider a few details of these arms :

(*a*) *The Articulated Hand.*—It consists of two shells of metal enclosing a cavity having the shape of the hand ; in the interior is a plate on which the fingers are mounted by means of hinges working on a common pivot. They are kept in a

closed position by springs attached to their bases. The fingers are controlled by levers or tendons of steel, T, which pass through a cam-plate C. To this cam-plate the steel cable is
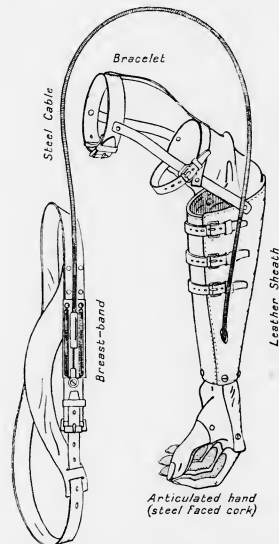
Fig. 105.—Mechanical Arm for an Amputation of the Fore-arm.

attached ; it works in a sheath, and is attached to the *breast-band* (Fig. 105).

(*b*) This latter is of leather, lightly made, and containing an elastic portion, consisting of springs which keep it lying

snugly on the chest. To the two ends of the breast-band are fixed the cable and the sheath respectively. Whenever the
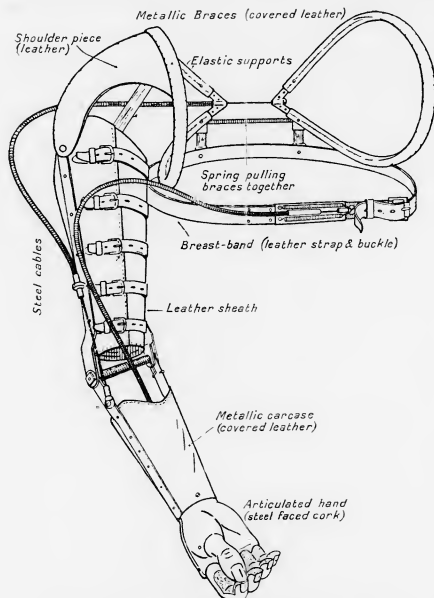
Fig. 106.—Mechanical Arm for Amputations of the upper Arm.

chest increases its girth by an effort of inspiration, or by the action of the muscles expanding the ribs, the cable actuates the cam-plate, and the fingers *gradually* open. There are no

sudden movements. Or the fingers may in the first place be in extension, so that the cam-plate acts with contrary effect.

(c) Various modifications of the greatest simplicity make it
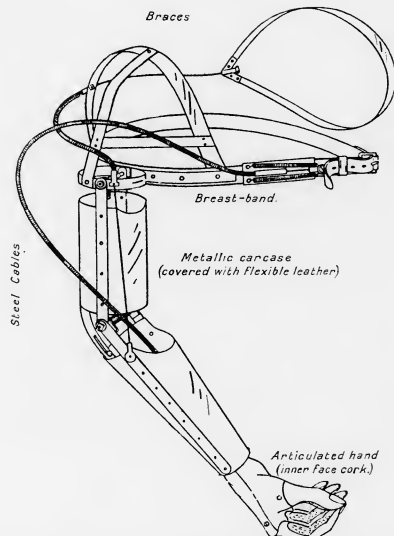
Fig. 107.—Mechanical Arm for Cases of Disarticulation of the Shoulder.

possible to adapt the articulated hand not only to subjects who have suffered amputation of the fore-arm, but also to those whose upper arm has been amputated, or even disarticulated. In these two latter cases a control for the *elbow*

is added : this control is actuated by the *shoulders* (by means of steel braces) and transmitted to the fore-arm by a second steel cable. The organs which replace a portion of the fore-arm, or the upper arm, or the whole limb, are made of sheet steel, covered with leather, or of leather only : they correspond to the indications of anatomy and physiology without prejudice

Fig. 108.—Crippled Typist using mechanical Arm.

to their mechanical qualities, which remain the most important. For the rest, the mechanical arm may be combined with the worker's arm, in the sense that the articulated hand may be mounted on the latter arm ; we shall then obtain automatism of movement, and also the great strength of the worker's arm (see Figs. 105 to 107 and further on).

CXXXIX. Employment and Qualities.—These mechanical arms may be employed by all persons who follow a business

or sedentary profession, without fatigue and without effort on their part. They fulfil one most important requirement ; they make it possible for those who have suffered disarticulation of the arm, or the amputation of both arms, to *take hold* of objects, and to perform the little actions of everyday life. For the artificial hand, with its shell, its cam-plate, its tendons, and its articulated fingers, capable of the most gradual movement, weighs in all only some eleven ounces : connected, by steel attachments, to a fore-arm, it weighs in all about one

Fig. 109.—Crippled Violinist furnished with a mechanical Arm.

and a half pounds ; while the whole arm never exceeds two pounds seven ounces. Yet it enables the wearer to lift a weight of fifteen to eighteen pounds between his flexed fingers and the opposing thumb ; to pick up with the finger-tips a pen, a pin, or a match ; to button his clothes ; to take out his handkerchief ; to write ; to turn over the leaves of a book. The hand opens by about $3\frac{3}{4}$ inches when the fingers are completely extended, by the effort of an inspiration or an expansion of the ribs which is not in any way painful or

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ment develops the chest. However, in the case of those
whose upper arm has been amputated the hand must be
controlled by the opposite shoulder.

The training required by the user of the mechanical arm is
very brief : in forty-eight hours the wearer is able to employ
it to perfection. And he may, by following the rules already

FIG. 110.—Officer provided with a mechanical Arm (Amputation of the upper Arm).

given in respect of the *sensory education* of the stumps, train
himself to graduate the efforts exerted by the metallic fingers,
to acquire an indirect sense of touch. In this way we have
known the wearers of such arms to operate, with sufficient
dexterity, the keys of a typewriter or calculating machine
(Fig. 108) or the keys of a piano, and even the bow of a violin
(Fig. 109).

Many officers who have suffered amputation of the upper
arm very near the shoulder have been fitted with mechanical

arms which have enabled them to mount a horse, to hold the
reins firmly, to hold the scabbard of the sword, and, more
often than not, to return to the army at the front (Figs. 110
and 111).

If it sometimes happens that a detail of construction seems
of a nature to favour the movements or the exertions of the

FIG. 111.—The same Officer on Horseback.

cripple, it is in no case difficult to work it out and apply it.
The mechanical arm, like the worker's arm, is adapted strictly
and wholly to the professions for the exercise of which it has
been designed. Theory and practice agree on this point :
it is impossible that it should not be recognised.

CXL. Other Models of Articulated Arms.—The prothetic
laboratory has nevertheless tested and investigated other
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reserved for prothesis in this popular work on the subject I should find it difficult to describe them all ; for which reason I have called the reader's attention to those whose merit has to me appeared incontestable ; whether from the tests made in the laboratory or from practical demonstrations before competent observers.

However, I will mention an American model, the carcase of which is of wood, and in which the mechanism is intended more particularly to exert efforts of traction. The appliance is heavy ; it is possible to lift objects only when the hand is in a horizontal plane ; it does not grip with sufficient force, and its price is high.

Other models are of use only to those who have suffered amputation of the fore-arm, as they are controlled by the flexion of the elbow. With these it is impossible to take hold of anything if the arm is extended ; or if the lever placed in the elbow acts upon extending the arm the contrary case obtains.

It must also be said that the majority of these types are made of wood, and are therefore fragile. To obtain the automatic action of the fingers is not everything if the force necessary for the performance of the actions in which the intervention of the fingers is indispensable is not available.

I have purposely refrained from discussing appliances in which this essential point has been overlooked ; as those, for example, in which the hand is opened by the rotation of a wooden disc which forms a second palm, a rotation effected by the pneumatic distension of a small rubber bulb. Here we have a total absence of natural appearance, of graduated control, of strength, and, I should be inclined to say, of any possibility of utilisation.

CXLI. **Functional Prothesis.**—The name of *functional prothesis* has been applied to the technical method which assists or replaces the performances of a muscular function in any case of infirmity. The term *physiological orthopaedy* would be more correct.

In this species of prothesis two different purposes are possible : either we have to *protect* the seat of the wound, and

support a limb which is definitely powerless, or the *neuro-muscular* condition is capable of *improvement* by the restoration of the function, favoured by a mechanical appliance, which has to be devised for this purpose.

A *static* operation in the first case ; a *dynamic* operation in the second case ; such are the modalities of functional

Fig. 112.—Splint for radial Paralysis.

prothesis. It is, therefore, diverse in its methods ; its applications are numerous, because the wounds in question are not all alike ; different lesions produce very different effects ; and, in short, every problem in this province of science is always a question of *a particular case*. Mechanics and physiology are here absolutely sovereign. They complete one another ; and we may add that one would be of little use without the other.

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we may add that one would be of little use without the other.

In principle the *static appliances* resemble the ordinary types of prothetic appliances, made of leather, and articulated ; they are protective ; they are adapted to fractures of the limbs, to cases of *pseudarthrosis*, to articular disorders, to cases of anchylosis. The *dynamic appliances* utilise the traction of springs or elastic bands to correct, and, at need, to

FIG. 113.—The same doing Office Work.

improve the motor condition of the hand, the fore-arm, the lower leg, the foot. They are employed in cases of *paralytic lesions, resections* of the elbow, etc.

The choice of the appliance and its mode of application should be inspired by simplicity, convenience, and *adaptation to the work to be performed.* Let us, for instance, consider the case of the *aluminium splint for radial paralysis.* A small plate of metal supports the hand, while the splint envelops

the wrist and keeps the supporting plate in place (Fig. 112). This arrangement is enough to restore strength and movement to the member involved : the subject gradually recovers almost the whole of his professional value (Fig. 113). Duchenne, of Boulogne,[1] gave particular attention to this problem

FIG. 114.—Improved Appliance for the Cure of radial Paralysis.

of the muscular paralysis of the hand and fingers. His models of appliances for elastic traction have been the subject of endless imitation. Invention, in devices of this kind, has become all but impossible. For these old technical methods I will refer the reader to the *Arsenal de Chirurgie contemporaine*[2] ; mentioning the very simple and economical models of Privat and Belot only as matters of historical interest.

[1] *De l'électrisation localisée*, Paris, 1861, 2nd ed.
[2] Gaujot and Spillmann, Vol. I., p. 602, *et seq.*, Paris, 1867.

In principle the *static appliances* resemble the ordinary types of prothetic appliances, made of leather, and articulated ; they are protective : they are adapted to fractures of the limbs, to cases of *pseudarthrosis*, to articular disorders, to cases of anchylosis. The *dynamic appliances* utilise the traction of springs or elastic bands to correct, and, at need, to

Fig. 113.—The same doing Office Work.

improve the motor condition of the hand, the fore-arm, the lower leg, the foot. They are employed in cases of *paralytic lesions, resections* of the elbow, etc.

The choice of the appliance and its mode of application should be inspired by simplicity, convenience, and *adaptation to the work to be performed*. Let us, for instance, consider the case of the *aluminium splint for radial paralysis*. A small plate of metal supports the hand, while the splint envelops

the wrist and keeps the supporting plate in place (Fig. 112). This arrangement is enough to restore strength and movement to the member involved : the subject gradually recovers almost the whole of his professional value (Fig. 113). Duchenne, of Boulogne,[1] gave particular attention to this problem

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Ingenuity of application, however, is of the greatest import-
ance ; above all when based upon physiological facts. Fig.
114, in this connection, represents an improved model which
makes use of the principle of the mechanical arm. The wearing
of this appliance restored the normal movements of the hand
and the wrist in the space of ten weeks. Which means that
by intervening in good time one often succeeds in arresting
nervous degeneration and atrophy.

Very rare are the circumstances in which functional prothesis
cannot assist the wounded man to *readapt himself to his work* ;
a fact which the physician and the orthopaedist must not
forget. It should be a guide to their experiments.

France has done much, in the person of her surgeons, her
physiologists, and her mechanicians, to diminish the misfor-
tunes of those who have been grievously injured by wounds
received in battle or by the accidents of industrial life. It
would have been strange if in this country, in which prothesis
had its birth, where in all ages the knights who have had a
hand blown off by a bombard have applied, so to speak, for
new members to our specialists—humble locksmiths or metal-
workers ; it would have been very surprising, I say, had the
ingenuity of our scientists and our artisans failed to manifest
itself with brilliance and distinction in a domain in which art,
science, and humanity meet together.

CHAPTER XII

THE RE-EDUCATION OF WAR-CRIPPLES (*continued*)

III.—PROFESSIONAL RE-EDUCATION

CXLII. **General Remarks.**—Functionally re-educated, and
equipped with the prothetic appliance which remedies his
infirmity, his mutilations of the fingers, or his loss of a limb,
the war-cripple may profitably be subjected to a professional
re-education properly so-called. I have already stated (§ 102)
that for the last forty years the methods employed in such
re-education have had a character of *charitable relief* in-
compatible with the spirit of industrial enterprise which is
making its influence felt. The Scandinavian institutions,
in which crippled children of both sexes receive a summary
apprenticeship, and work in private workshops, which ignore
all the laws of economics and the conditions of production,
constitute models which should *not* be copied where soldiers
are concerned. For these latter are *adults* ; they usually
know a trade ; they are far from being abnormal or outcasts.
It would be absolutely unpardonable did such a confusion
of ideas persist in the minds of our organisers. And it would
be absolutely contrary to the reality to suppose that these
wounded soldiers are incapable of being utilised, in a methodical
manner, in industrial pursuits. Finally, in almost all cases
they must be free to manage their own affairs, to work in work-
shop or factory, in town or country, unsubjected to the
slightest constraint.

For these reasons any work of true re-education should have
recourse to a strict technique which gives the wounded soldier

a professional orientation, which measures and disciplines his strength, and analyses and adapts his movements to the prothetic appliances and the tools which he employs ; and, in a word, obtains the maximum output from the latent reserves of individual energy.

In Germany the Munich Institute, attended by three or four hundred young men, has effected a certain improvement upon the institutions already mentioned ; and this because it aims at a regular apprenticeship. However, the general spirit of the movement is not very different. It is still a charitable institution for the assistance of children. Since the beginning of this war the Germans and the Austrians have endeavoured to establish a form of organisation better adapted to the needs of the wounded soldier, which in many respects reproduces the form which I have been recommending for the last two years.[1] Let us therefore sum up the elements of this scientific re-education.

CXLIII.—1. **The Education and Evaluation of Efforts.**— In this connection particularly the analysis of all the physiological and mechanical factors of labour becomes of decisive importance.

From the physiological point of view we determine the conditions of pace, force, and the daily working hours which will obtain the greatest output from the wounded soldier. The efforts of the muscles are *graphically* registered, so that we can appreciate their intensity and regularity, and their succession in space and time.

This analysis allows no anomaly to escape it, such as might be caused by some infirmity which is hardly apparent ; or by an incorrect prothesis, or by the incapacity of the subject. From this circumstantial examination we obtain information of *great practical value.*

To begin with, we learn that if the stump of the upper arm is less than 5 inches in length it will not permit of continuous and regular work of any duration unless it has been functionally re-educated to the desired degree.   Otherwise the fatigue

[1] Jules Amar, *C. R. Acad. Sc.*, Vol. CLX., p. 559, April, 1915.

would be so great that the worker could not long hold out. A thigh-stump less than six inches in length renders locomotion difficult for those who have to walk frequently on account of their work.   The factor of *fatigue* is of the greatest importance, as it enables us with certainty to appreciate the professional capacities of wounded and mutilated soldiers, whatever the orthopaedic appliances with which they are equipped. Because they have not taken this factor into account the amateur re-educators have seen their schools, if I may call them so, deserted by those who confidingly repaired to them for lessons which should profit them in the future.

Let us take the case of an arm, one of whose segments is powerless, or even of a prothetic arm.   The tracing made by the tool—file, plane, or hammer—will show that the intensity of the efforts is diminished, revealing a certain incapacity to press, or thrust, or control the tool (Fig. 115).   In the *irregularity of the curves* we perceive a hesitating muscular activity as yet imperfectly re-established, especially if the process of functional training is only commencing.   If this activity, even though enfeebled, is not restrained by an artificial limb, the dynamographic curves are all *similar,* and the tracings assume, if we may say so, an *individual, personal* character, by which we may recognise the *degree of incapacity* for work.

By making an *average* or *mean* tracing, which is a summary of the curves produced by *normal* workers, skilfully exercising the same craft ; and by remembering the fact that unequal and dissimilar curves betray *simulation*, we shall obtain a scientific basis for estimating the *incapacity to perform work*, and for *unmasking the malingerer.*   Any other method appears to me fallacious.

I have always recommended the introduction of a technical method possessing this undeniably objective character in the *expert investigation of industrial accidents*, and the determination of military *pensions.*   It is inevitable that such a method should be adopted.

Any attempt on the part of an infirm subject to increase his effort involves difficulties of respiration, as is seen in Fig. 115.

If the curves are *flattened out*, by rotating the recording cylinder at a quicker rate, we shall be able to perceive the details more plainly.   The effort of the left arm commences
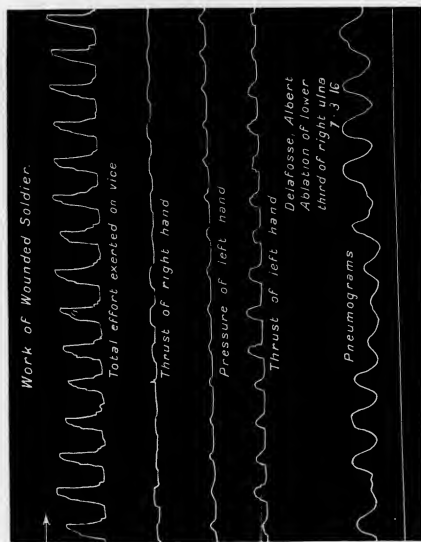
Fig. 115.—Graphs produced by filing Metal. (The Subject was suffering from Weakness of the right Arm, due to partial Ablation of the Ulna.)

before that of the right arm, even in cases of infirmity, and the latter fulfils a function of *support*, particularly if it is an artificial arm (Fig. 116).   The conception of the *orientation* of the arms when working results from this investigation, and it is
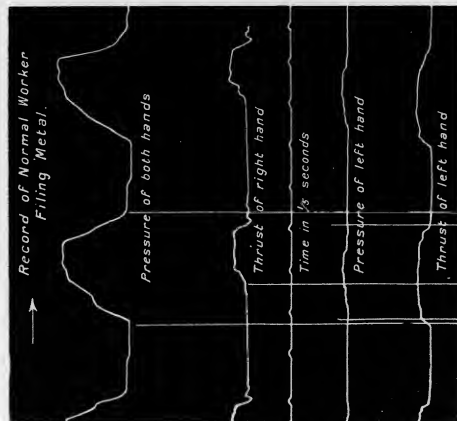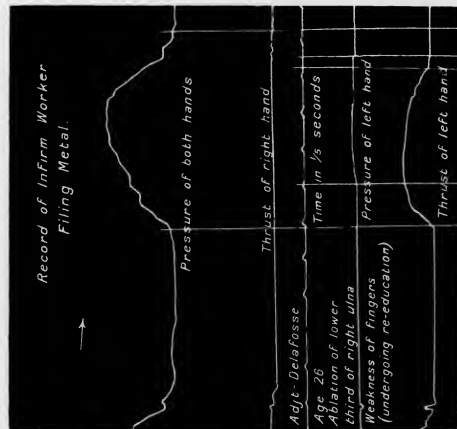
Fig. 116a.—This Subject is of the same Age and has had the same experience as the normal Subject.

Fig. 116b.

precisely of this investigation that the adaptation of prothesis to professional education consists. The healthy limb should

Fig. 117.—Analysis of Work and Fatigue in the Case of an Armless Worker.

as a rule *guide* and *control* the tool, the artificial or infirm member serving only as *support* (Fig. 116a).

In cases in which the *upper arm* is amputated (Fig. 117), we may deduce from the records the advantages of this or

that position as regards the development of the maximum effective power. In such cases there is not and cannot be a

Fig. 118.—Graphs showing the Improvement in the Work of a Subject who has suffered Amputation of the Humerus, according to the Angle of the metallic Elbow and the Length of the Shank of the Fore-arm.

symmetrical action of the arms; and the inequality which necessarily results diminishes the output of work.

In reducing this depreciation to a minimum, it is by no means a matter of indifference whether the prothetic member

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In reducing this depreciation to a minimum, it is by no means a matter of indifference whether the prothetic member

acts upon the handle or the extremity of the tool ; whether it exerts the motive force, or is the directing organ ; whether the articulation of the elbow is no longer free ; or, if the articulation is *anchylosed*, whether it is fixed at this angle rather than that ; or, lastly, whether the stump transmits its effort to a long or a short lever (Fig. 118). Prothesis must therefore collaborate in the process of re-education, and must be intimately connected with professional technique. No considera-

Fig. 119.—Forming a Left-handed Worker with the self-registering Jointing-plane.

tions of cost must be allowed to prevent the employment of the appliances best adapted to utilise the entire social output of the wounded soldier.

CXLIV.—2. **Education of the Movements.**—**The Formation of Left-handed Workers.**—I have stated that the artificial arm fulfils, as a general thing, a function of *support*, the sound arm doing the effective work. This fact is self-evident in cases of amputation of the *left arm,* when the right arm retains its normal activity ; at least, it is so in right-handed subjects.

Fig. 120.—Education of the Movements by means of the dynamographic Hammer.

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Fig. 120.— Education of the Movements by means of the dynamographic Hammer.

But in the contrary case it is *absolutely* necessary to re-educate the left arm, so that it may acquire the strength and dexterity of the amputated member. This is easily effected : in the first place, by means of the *self-registering jointing-plane* (Fig. 119), the patient follows the adaptation of his appliance and the quality of his movements, which he trains in strength and accuracy, increasing his pace and his
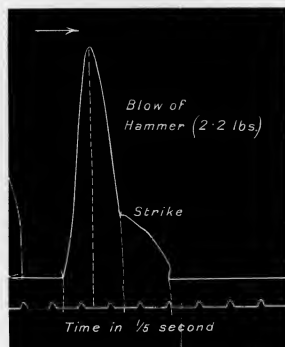
FIG. 121.

working effort day by day. Then he assures himself that his left arm is beginning to strike a very quick blow with the *hammer*, and that he can just crush a morsel of chalk placed upon an anvil, despite the amplitude of the movement.

The *dynamographic hammer* (Fig. 120) gives a graphic record of the elements which form this example of *physiological pedagogics* (Fig. 121) : the amplitude of the hammer-stroke is measured by that of the curve ; the duration, *t*, is recorded on the cylinder ; the force exerted is expressed by the pro-

duct, $m\,v$, m being the mass of the hammer and v its velocity.

The trajectory of the hammer is measured by the length of cord t unwound from a large aluminium pulley ; this actuates a small pulley mounted on the same axle, and controlled by a spring which re-winds it (Fig. 122). The cord which runs from the spring to the small pulley moves the inscribing needle upon the recording cylinder.[1]

Lastly, we must *accustom the left hand* to trace an *oval* of .8 inches by 1 inch, and a square whose side is 1 inch, which are cut out of a sheet of copper. This stencil is placed on the paper, and the edges of the apertures thus formed are followed by means of a pointed pencil or stylus. The repetition of these different exercises, at an always increasing pace, guarantees the formation, in 5 or 6 weeks, of skilled left-handed men, able to work, write, play, and draw with accuracy.

Educated or intelligent subjects acquire this capacity in a very short time. Agricultural labourers take longer to
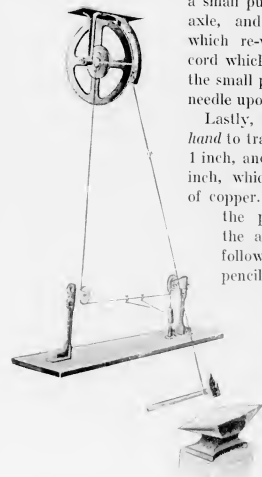
FIG. 122.—Self-registering Hammer.

train, and one is obliged to act upon their minds by

[1] The ratio of the pulleys is 1 : 15, so that the amplitude of the curves, multiplied by 15, gives the trajectory of the hammer. From this and the registered duration of the stroke we deduce the velocity per second, v, of the hammer. And as we know the weight, w, of this tool, we can calculate the mass, m. Hence the product $\dfrac{mv}{t}$ or $\dfrac{w}{g} \times \dfrac{v}{t}$ (g being the value of gravity).

Y

frequently repeated examples, and by the frequent handling of agricultural implements.

All things being considered, a certain clumsiness will be displayed by these newly-made left-handed workers, which will take some time to disappear ; but it will be much less perceptible in callings requiring the exertion of strength than in those which demand skill and dexterity, and in the performance of clerical work. Nevertheless, the faculty of adaptation is of superlative importance, and some cripples will be able to use their stumps as well as their sound limbs. We are acquainted with extraordinary examples, to which we shall not further refer, since such phenomena are not in accordance with natural laws, and we are concerned exclusively with these.

CXLV.—3. Physiological Education.—Parallel to this

series of observations we must pursue another whose aim is the *investigation of respiratory exchanges*, in order to deduce from these the degree of fatigue induced. In one position or another of the body, or the tool, or the artificial arm, either a waste of energy or an economy will be revealed by such measurements.

Hence we shall obtain information of very great importance in the formation of the apprentice and the worker : a true *object-lesson* for the worker who takes pleasure in observation and seeks enlightenment, and, above all, a guarantee against overwork, and an indication of the danger of breathlessness, or dyspnoea.

I do not insist upon the other physiological factors, such as the *size, weight*, or *strength* of the subject, or the condition of his *reflexes*, and the swiftness of his reactions, which it is possible to improve. These *individual constants* also are a guide to the choice of a calling. They will be determined when the functional re-education is completed. If this latter were not judged to be necessary we should simply determine the subject's *personal equation*, his *vocation*, his *tastes* and his *previous calling*. A worker who has served the same employer for a number of years is taken to be a well-behaved and respectable workman.

The individual character must not be neglected, for it affects the finding of employment. It also reveals another aspect of working-class life—the cares of a family. When his environment, his wife and children, do not leave the man the peace of mind necessary to good work, when illness or grief has descended upon the home, the deepest wells of human activity are poisoned, and there is a certain disorder in his actions and his ideas. Thus character is visibly affected, and for the worse, despite the exercise of the strongest determination.

The wounded soldier, then, receives an education which regulates his efforts and his speed, disciplining his movements and adapting them to exact operations, every detail of which has been studied. He is spared all superfluous fatigue, all waste of time and energy.

This economy, and the skill and ability of the worker, are always increased by his intelligence : which, if it was not previously awakened, will be aroused by the *theoretical instruction* given during his re-education ; a course of instruction which will be in harmony with his chosen *professional orientation*, and which will give him a certain knowledge of mechanics, design, his own language, and accountancy ; or again of agricultural chemistry, mechanical cultivation, rural economy, etc. And from the sum of qualifications and inclinations, recognised, encouraged, and evaluated, we deduce the direction to be followed by his apprenticeship or re-adaptation, and the *social value* of the worker, the *human factor* only being considered.

CXLVI.—4. The Adaptation of the Tools Employed.—

Now in addition to these *moral* and *physical* aptitudes, which are appealed to and encouraged, and which, in a sense, are given first place, we must consider the *mechanical factors* of labour. To begin with, these factors are determined by the investigation of the *principal movements* necessitated by the exercise of a craft. For, as a rule, the worker merely repeats, without important variations, a certain number of gestures, in which the different segments of the various limbs occupy

well-defined positions. From this investigation, which may be
simplified and rendered as exact as possible by cinematography,
we deduce the *professional hierarchy* of the two members,
upper or lower, the preponderance of one over the other,
their separate or combined action, the order of their succession
in time, and their trajectory in space.

No basis on which we could undertake the *re-adaptation of
the wounded soldier* and his *orientation* toward this or that
calling could be nearer the truth than this.

In the second place, the mechanical factor involves the
choice of tools, and the employment of machinery, motors,
and special devices, which, in workshop or factory, will sur-
round the war-cripple with professional conditions favourable
to his useful employment. It may well be imagined that a
mechanical improvement may modify the control of a machine,
facilitate the execution of a process, or simplify the movements
of the war-cripple, and thereby be of considerable service
to him.

This or that operation which demanded the use of both hands
might be effected by one only, and would occupy a great number
of "armless" workers. Another, in which a small motor
might supplement the strength of the worker, would serve
the same purpose. If, for example, the accelerator or change-
speed gear of a motor-car or lorry were controlled by hand,
by means of a convenient lever, the one-legged chauffeur would
be able to remain at his old trade ; and he would be given an
artificial leg instead of a " pestle."

The tools and implements are numerous in which mechanical
substitution is possible at a very slight expense. Controls
may be grouped so that the worker need not move from place
to place ; the weight of the work in hand may be counter-
poised ; and the means of adjustment of machine-tools (lathes,
drilling-machines, etc.) may be improved.

Thus it occurred to me to adapt for the use of one-armed
men the punch which is employed for perforating railway
tickets. Instead of holding the ticket in one hand and the
punch in the other the one-armed man hangs the implement
on his waistcoat, by means of two patent fasteners, or a hook ;

a small spring holds the ticket in place, and it suffices to press
the lever in order to work the punch and the date-stamp (Fig.
123). This modification costs a few pence, and there are
several thousands of posts on the French railways which might

Fig. 123.—One-armed Man using Punch perforating
Railway-tickets.

be filled by one-armed soldiers, the normal workers being
employed in other branches of the services.

The Paris-Lyons and Mediterranean Railway Company,
which gave ear to my proposals on this subject, has adopted
the course indicated, anxious to promote the welfare of those
splendid fellows, the French railway workers.

Such innovations should receive continual encouragement,

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and should be stimulated, if need be, by *prizes*, and this particularly in the agricultural world. One result will be a *machinery of re-adaptation* in the interests of war-cripples, for which they themselves will provide the physiological data, and which it will be necessary to introduce in practice. But care should always be taken not to complicate this machinery. When the war-cripple has been equipped with his *worker's arm*, with the universal holder and universal ring, there are few circumstances under which special tools or implements are necessary to him ; he does not experience the hesitations and the delays in " getting started " of which an employer, justly concerned as to the time-sheet, might be tempted to suspect him.

In prothesis, *the multiplication of organs of prehension is, both industrially and physiologically speaking, fallacious.*

In the Danish institutions, or in that of Munich, the cripples make use of tools and implements adapted to their infirmities. But in these institutions neither time nor money matters, a point of view easily understood, but one which we are far from sharing.

If I had proposed to discuss the problem of the work of the *blind*, or of men who have lost *both arms*, I should have described the special equipment which is adapted thereto, and which, for these unfortunates, is absolutely indispensable. But this would have led me away from my present programme.

I shall therefore reserve for the end of this volume a brief survey of the subject of *relief* by means of employment.

CXLVII. **The Advantages of Scientific Organisation.**— 1. THE PHYSIOLOGICAL VALUE OF THE WAR-CRIPPLE.— This method of organisation, whose exactness is beyond all doubt, has often seemed too rigorous and too scientific, and has aroused the fear that it would be difficult of application. This fear is not only regrettable ; it is totally unfounded. The scientific method is as simple as it is reliable. After a preliminary stage of falling into step, which requires a certain amount of attention, it can be applied with great rapidity. I have observed some three thousand persons, of all ages and all

stations, and I have never required them to subject themselves to any experimentation which was in the slightest degree

FIG. 124.—Case of Ablation of the four Fingers (Carpenter).

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Example of Certificate of Industrial Qualifications.]

HIGHER SCHOOL OF RE-EDUCATION.

CERTIFICATE OF INDUSTRIAL QUALIFICATIONS.

DIRECTOR ....

TELEPHONE No. ....

CITY OF ....

...........................19.......

Subject No.	Physical Characteristics.	Psycho-physiological Characteristics.	Industrial Qualifications.
Surname	Weight	Extent of education—	Condition of re-apprenticeship........
Christian name	Height—erect (E)	General	
Age	„ —seated (S)		
Military rank	Thoracic co-efficient $\left(\frac{A}{D}\right)$ ...		
Address	Liberty of movements........	Technical	Tendencies to be observed in work
Wound received on the......			
Place			
Cause		Condition of reflexes............	
Region affected	Length of sound limb...........		
	Dimensions of stump or stumps...		Probable duration of re-education...
Operations			
	Useful muscular power........	Personal equation...............	
Tissues injured...............			Diminution of daily output...
		Vocation..........................	
Complications	Physiological condition of subject...		
		Tastes	General remarks............
Results			
	Loss of functional capacity.....	Character	
Previous profession.........			
Persons dependent upon him—		Suitable profession............	
Wife	Prothetic appliances supplied........		
Children			*(Signed)*
Parents			*The Director.*

mental and physical aptitudes, his profession before the war, the new inclinations which he may reveal, and his family responsibilities, are collected *in less than an hour*.

FIG. 125.—The same at Work, thanks to special artificial Fingers.

These various elements, carefully verified, with all possibility of dispute eliminated, are tabulated on a form which consti-

tutes the subject's *certificate of industrial qualifications* (see above). This certificate is *personal*. Nothing is wanting but an indication of the professional capacities resulting from *re-apprenticeship* or *re-adaptation*. This will be added later.

Information of this nature, obtained by the methods described, inspires confidence ; it enables the interested party to feel his way, to choose his path ; a more and more curious observer of an inquiry which he understands, he emerges from it consoled and encouraged ; he feels as though he had been freed from that obsessive burden, *anxiety as regards the future*. Science has worked within him a moral transformation of the happiest nature, which he does not seek to dissimulate.

And not only does the future workman or employé derive from this examination a real moral advantage : he also becomes aware of his *precise social value*. The employer, too, is introduced to this unsuspected sphere, in which he sees forces recuperated which he believed to be destroyed ; he feels, above all, that they are trained to serve with a *maximum of output*. For the rest, the certificate of qualifications mentions the loss of daily output resulting from the wound, estimated by experiment in connection with a measured and recorded task.

CXLVIII.—2. THE OUTPUT OF PROTHESIS.—In the case of those who have suffered the loss of a limb by amputation the evaluation must be based upon the gravity of the mutilation and the resources of prothesis. Are some of the phalanges lacking, or even all the fingers, the *thumb excepted ?* The loss of industrial capacity will be from 5 per cent. to 15 per cent., according to the trade or craft, on the condition that the missing phalanges are skilfully replaced by prothetic segments.[1]

The carpenter or small machinist is then able to resume his accustomed trade without appreciable inconvenience (Figs. 124 and 125). He himself succeeds in re-educating his sensi-

[1] It is difficult to make up for the loss of a *thumb*. The Romans exempted persons thus mutilated from military service. However, in the case of callings which do not demand great efforts of digital pressure or compression prothesis has succeeded in supplying fairly useful artificial thumbs.

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Fig. 126.—Marble Cutter and Sculptor practising their Crafts at Home.

amputation of *one hand* rarely forces a man to change his
profession ; and this also applies to the loss of one *fore-arm*,
when the stump measures more than 1·6 inches from the internal

crease of the elbow.   The loss may be remedied by the worker's
type of fore-arm, or by the lever type.   The wearer's vocation
will decide the choice, and it is the part of re-adaptation to
exploit the war-cripple's resources of functional power.   He

Fig. 127.—Fitter working in his Employer's Workshop.

may hesitate, may become discouraged, may distrust himself.
The facts, clearly and adroitly displayed before his eyes, pro-
duce in him the determination to *try*.   And this is everything.
The war-cripple who wants to try is already near success.
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fitters (Fig. 127), bookbinders, tailors, printers—have been able to resume work after a brief training ; but it was previously ascertained that their strength remained in a degree

Fig. 128.—Faulty Prothesis (filing Metal).

necessary to the exercise of their callings. The amputation of the *upper arm* demands a more laborious re-education, which only the scientific method can guarantee. In the case of these major operations the loss of output is always from 15 per cent. to 30 per cent., despite a superior prothesis.

When this is defective, misconceived, or of an empirical nature the output is considerably reduced. I find, for example, that in one " School of Re-Education " men are taught to file by squeezing the handle of the file into a *ring* (Fig. 128). Here, in the first place, is a mechanical fault, for the ring has no articulation which makes it possible, as with the *universal holder*, to point the tool in any given direction ; secondly, only a fraction of the power of the stump is utilised. Similar details, all of which have their importance, show that re-education must not be a matter of groping for results, or of chance.

For the rest, what conceptions can the instructors obtain to help them in the task of *professional orientation*, save those which the observation of prothesis in action, and an efficacious prothesis, enables them to form concerning the *present value* of the war-cripple, and the difficulty of his craft ? I will mention a sufficiently striking case. A benevolent society sent me a patient whose left upper arm had been amputated, leaving a stump 3·9 inches in length. He was a *maître d'hôtel*, and he was sent to me to learn whether he could not learn *Russian* with a view to becoming a hotel interpreter. I need not describe the amazement of the wounded man when I advised him to resume his old calling. Yet he did so, and with success. Provided with a good worker's arm, he was easily able to hold his knife, and display his skill in the art of Vatel. The same thing happened in the case of a foreman butcher.

Agricultural workers or farmers, provided one stump is of greater length than 4·8 inches, should be able to endure all the fatigues of their calling. The universal ring and the hook are of inestimable value to them. And always, or almost always, the artificial organ will serve to *support* the implement, or to bear upon it. Experience leaves me in no doubt whatever upon this point : but our peasants must be interested and instructed. On the other hand, if a man is forced to desert his original calling, the *quality* of his work will inevitably suffer. This is a truth which we must have the courage to affirm, and which cannot diminish the merits of *scientific re-adaptation* to work.

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CXLIX.—3. SIMPLICITY AND RAPIDITY.—To all these proved advantages of the new method of re-education, let me add the testimony of engineers and physicians who have been applying the method for the last eighteen months. A period of *4 to 5 weeks* in my laboratory enables them to familiarise themselves with the technical details of the appliances provided, and the methods of investigation and professional orientation employed.

Of the many institutions of which they are the directors, in France, Italy, England, Canada, and Russia, I will make particular mention of the École Supérieure of Bordeaux, the Roman school, and the Milan Institute. These establishments are attended by an average of 75, 80, and 130 war-cripples ; but they provide a *real* re-education, whose results are reliable. The number of the pupils is tending to increase, and it is found that the certainty of the method employed exerts a decisive influence upon the enthusiasm of the candidates.

The benevolent institutions which have been scattered here and there at the inspiration of empiricism, and which are striving to attain the same object, are wasting time and money ; they are condemned to disappear, unless they strike tardy roots into a better-prepared soil.

However, I will mention the workshops for the re-apprenticeship of subjects with mutilated fingers (Fig. 129) ; they are economical, and facilitate the work of orientation.

In the meantime the *scientific system* has proved its qualities, which we may characterise as follows :

It quickly and efficaciously re-educates the infirm or mutilated soldier ; it guarantees the endurance of the workers it has trained, and also their rational utilisation, and their *moral;* the information which it gives the employee is sincere, and it establishes a feeling of confidence ; it disciplines the professional activities, and inculcates habits of method and order.

To fail to realise all the practical and effective truth contained in these principles is to be gravely misled, and to incur the heaviest responsibilities.

FIG. 129.—Workshop for the Re-apprenticeship of War-Cripples as Goldsmiths and Jewellers.

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FIG. 129. Workshop for the Re-apprenticeship of War-Cripples as Goldsmiths and Jewellers.

CL. The Methods of Scientific Organisation must now be considered. As re-education cannot be *obligatory* for all, nor confined to a single region,[1] an active propaganda should be carried out everywhere; in the family, in schools, and in public meetings; in order to induce the hesitating war-cripple to enter his name without delay for admittance to the establishments organised for his benefit, in which are accumulated such treasures of experience, science, and human solidarity as no other nation could offer him. From the day of his entry until the day when employment is found for him in commerce, industry, or agriculture, there will be nothing lacking in the consideration and the sacrifice to which he has an absolute right.

I have said, and I repeat[2]—until, I hope, I have made myself understood—that professional re-education continues and completes the functional education. The two together constitute an undeniable *physiological unity*.[3] But it is also necessary that they should form a *psychological unity*, in the sense that the wounded soldier should be prepared for his future calling *from the time he enters the hospital*. To this end he will be given to read a sort of *guide* and *prospectus*, in which will be described the kind of infirmity from which he is suffering, the professional destination to which it points, and the positive results of re-education and re-adaptation. Professors of manual craftsmanship will visit the hospital to give lessons with cinematographic demonstrations. Above all the instruction given should be concrete and realistic, consisting of facts rather than of words. Let no promise be made if there is risk of disappointment on the morrow. Let the wounded soldier feel himself sustained by knowledge and experience

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[1] The law of France to-day admits, as the result of the fortunate intervention of M. Pierre Rameil and the report of M. Brunet, both deputies, that professional re-education is *obligatory* in the case of any victim of amputation who has the right to a military pension. Let us note with Monsieur Rameil that this re-education is the *right* of the wounded soldier, a right which places the obligation rather to the charge of the State. (Concerning this interesting discussion see *l'Officiel*, session of 14 April, 1916.)

[2] *C. R. Acad. Sc.*, 26 April, 1916, Vol. CLX., p. 559.

[3] The physiological effects of professional exercises are now beneficially utilised in the Austro-German hospitals under the name of *Arbeits-therapie*.

united to probity, and by the material help of a generous country. It is important to banish from his heart the bitterness which is always left there by charitable assistance.

To sum up : to commence the process of professional re-education as early as possible ; to set the bait, as it were, in the hospitals, by the visits of competent and highly tactful teachers, by lectures and ocular demonstrations whose teaching cannot be resisted : such is the indispensable programme.

In practice professional re-education will not reach all our wounded soldiers. Some, who possess a certain competence, will return to their homes, and will find some means of occupying themselves ; well equipped, they can *re-adapt themselves to their work* in their own way. Being educated, they will attach themselves, by the ties of intelligence and determination, to the general professional life of the country.

Others—a very small minority, I hope—will hide themselves away, in indifference and idleness, which will inevitably drag them down into poverty. These disastrous habits have had time, alas ! to assume a distressing development during the years in which nothing has been done for the organisation of the work of wounded soldiers ; while private institutions for re-education have exhausted themselves in futile groping. *Monetary assistance* has been abused, since it has been given without the definite condition of being the *reward of work*, and thereby a spirit of idleness and mendicity has been created of which it will be difficult to cure the always interesting victims of the war.

This evil has been enabled to increase to such a point (and I have investigated it very thoroughly in the wounded soldiers whom I am studying, in this connection among others) that it has seemed to me *irreparable* ; and I recently complained of it[1] in the hope of opening the eyes of those who, I can readily believe, have closed them to the things of this world.

But we must behave as if they would one day open them, and describe the realities.

[1] *Revue Scientifique*, p. 367, 1916.

CLI.—Schools of Professional Re-education.—The great majority of wounded soldiers, instructed and stimulated by example, will resort to the *higher schools of re-education*, thus denominated in order to indicate that a pedagogic and technical method will be employed in them, with superior guarantees as to their organisation. One will be created for each *economic region*, the nature and importance of the regional products, and the resources of the producers—in the shape of plant and equipment—serving as guide. For France I propose eleven regions, that is to say, eleven schools, distributed among the cities of Paris, Rennes, Lille, Nancy, Lyons, Limoges, Bordeaux, Toulouse, Marseilles, Algiers, and Tunis. The original grouping here indicated is by no means absolute, although it seems to me rational. One might replace the cities mentioned by others, combining economic elements such as our departments in fresh units.

Now the *regional* organisation appears in this connection to be opposed to the *departmental* organisation ; or, at least, so some have supposed. The truth is quite otherwise. It is because there are so few *centres* that numbers of small schools and workshops of re-apprenticeship, scattered all over the country, have been born of private initiative. They have followed the movement of the wounded men emerging from the military depôts ; for all these men, once discharged and restored to civil life, have tried, more or less, to work and to find situations. Generous people—whom we must not tire of praising in proportion to the indifference displayed by official figureheads—have encouraged them by pecuniary relief, by recommendations to employers, and by the improvised institution of special workshops. The Conservatoire des Arts et Métiers has several such workshops, affiliated to the laboratory of which I am the director, if only for the sake of professional orientation and the assistance of my prothetic department. Can these small departmental organisations be made to harmonise with the existence of large regional centres ? *Certainly*, provided these latter undertake the work of functional re-education, examine and provide appropriate prothetic appliances, and draw up *certificates of qualifications ;*

after which they will send the wounded and mutilated soldiers to their respective departments, where they will be near their families ; that is to say, to the *local workshops*, whose function is then complementary and decisive.

CLII.—(a) THE ORGANISATION OF A CENTRE OF RE-EDUCATION.—The Higher School of Re-education should exist side by side with these elementary workshops. Here follows an account of its organisation in France, as it should have been from the beginning, and as the regions and cities of which I have already spoken—Bordeaux, for example—have made it as a result of my indications.

Each school possesses a *technical department* which prepares the *certificates of qualifications*, attends to all medical and orthopaedic requirements, and undertakes the general physiological examination which the certificate itself requires. In the same building are installed *workshops*, adapted to the practice of the ordinary trades and crafts of the region. These will necessarily be of many kinds, in order to attract as many pupils to the school as possible. The following trades in particular will be taught :

Orthopaedy ; mechanical engineering (fitting, tool-cutting) ; industrial design ; photography (retouching, enlarging, and printing) ; shoe-making ; harness-making ; saddlery ; electrical fitting ; tinsmiths' work and the lesser mechanical crafts ; typewriting ; the management of agricultural machinery and small motors ; toy-making in wood ; the making of hands and feet for artificial limbs ; carpentry.

In some centres (Jura, Vienne, and Haut-Vienne) the practice of the lapidary art and ceramics will be developed, which might yield France a considerable advantage over other countries. If the numbers of those who have lost a lower limb is large, and a change of trade becomes necessary, tailors and weavers will be trained. But in general we must avoid keeping at the school those war-cripples who are able to resume their old trades.

The *direction* of the school is entrusted to a competent physician, assisted by an experienced engineer. Both must

be tactful, and capable of judgement and reflection. Their physiological knowledge will be in request every moment.

The physician is responsible for functional re-education, prothesis, and orthopaedy, and observations relating to the psycho-physiological qualifications of the wounded soldiers. It is impossible to divide these different services, to which the assistants and instructors are appointed. The victims of amputation work at repairing or transforming prothetic appliances, and installing workshops. But work of this sort should not be specialised, or serious disappointments may occur.

The engineer, for his part, assisted by a few good professors of the manual crafts, or by foremen, has to supervise the general and technical instruction of the men, and divide them into professional categories. He keeps a watch upon the movements of his patients and the good condition of their artificial limbs, and he explains the best mode of employing them. I have always remarked that the victim of amputation very quickly completes his sensitive education, and shows, in the handling of his tools, a dexterity which amazes his instructors. He is for them the occasion of many living object-lessons, for experience, in this connection, is the only guide.

The teaching is not confined to workshop practice ; *theoretical* courses are provided ; complementary instruction in science and literature increases the average level of intelligence, and enables the brain to co-operate with the arms, when the latter are uncertain.

CLIII.—(*b*) PROFESSIONAL ORIENTATION.—In our days, when man has ceased to be an active part of the mechanism of the wonderful *machine-tools* of industry, to become a mere agent of starting and stopping, in whom automatism has reduced to a minimum the graduated and voluntary activity of the muscles, we must train the greater number of our war-cripples for economical trades, which are not fatiguing, and are often remunerative. I imagine that if small motors of 2 to 5 h.p. were placed in the hands of our farmers they would live more prosperous lives, and would render more fertile

and productive the soil which has been so unhappily neglected.

An examination of agricultural implements, with a view to their adaptation to the use of war-cripples, has become a necessary undertaking, but has not sufficiently attracted the attention of the State. When he first enters the school the farmer invariably informs me, if he has lost an arm, that he can no longer perform any agricultural operation, unless to give food to the live-stock. But when he has been re-educated, when he is equipped with the worker's arm, with the universal holder and ring, he accustoms himself, first of all, to the use of the dynamographic shovel : then he employs, turn by turn, the ordinary spade and shovel, leaning on them and pressing them into the soil as they should be pressed ; then he strikes and pulls with the mattock, or presses and pulls the hoe or rake. In a few days after his return to the country the farmer writes to tell me that he is performing all his agricultural tasks without assistance from any one.

In certain parts of Central France—in Lozère, Corrèze, Cantal, or again in the Vosges—the peasant might devote the slack season—the winter—to making wooden toys : a craft in which his ingenuity, his habit of making something of everything, and of doing everything with his own hands, would find useful scope. This toy-making industry used to be localised in Germany, in Nüremberg and Fürth. Already the Italians of the North and the Swiss have reacted against this monopoly. We, too, who possess the wood—usually beech— and the most skilful labour, ought to follow this example, which costs so little in the matter of initial outlay : a knife, a saw, sometimes a small lathe, and a hammer.

Even in navvy's work, road-making, etc., there is room for one-armed men. I had several yards of a path paved by such a worker, who employed a pneumatic paving-beetle, known as a *demoiselle*. It appears that this sort of work suits the one-armed man far better than it does the one-legged man, although the reverse is true of the removal of soil. Two-wheeled barrows, which are easy to guide, are obviously indicated for work of this kind.

In all the trades or crafts hitherto mentioned the knowledge of the movements and the efforts required of the worker presupposes a knowledge of the use of tools. This is a very important point. Of course, the director of the workshops

FIG. 130.—One-armed Mechanic making a Forging.

cannot contrive to be omniscient, but his general education and his experience should prevent him from making mistakes, or leaving to his assistants the task of selecting the trade or craft to be followed by the war-cripple. Otherwise it would be

better to induce him to relinquish his position. He must realise that the one-armed man is in a position to adopt the calling of a *mechanician* ; he can file, use and set a saw, handle the shears and the chisel, grind and set tools, drill holes with the centre-bit and brace, and employ the tap and screw-plate or dies. The sound arm will wield the hammer (Fig. 130).

FIG. 131.—Wounded Soldier working the Jointing-plane.

Only the *lathe* will present any real difficulty. But this depends on the kind of lathe ; some can be controlled without much difficulty (the capstan lathe, for example).

The war-cripple can also become a wood-worker ; he can saw, plane, assemble and glue parts, drill, mortice, etc. (Figs. 131, 132).

To-day the intelligence of the worker is an important factor, which is seconded by the full force of technical experience. This enables us to destine a fairly large number of war-cripples

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to work with machine-tools, which will in future be employed by the industrial world even more widely than at present. The mental vivacity which is one of the characteristics of the French people will greatly contribute to this professional adaptation.

FIG. 132.—One-armed Worker cutting Wood by means of a Rip-saw.

If, on the other hand, we bring to these questions that determination to realise the facts which is incumbent upon us, we perceive that only an exasperating prejudice has prevented the majority of crippled workers from obtaining employment, and that it has affected soldiers more than civilians. It is truly to offer an insult to glory to exclude it from our work-

shops, humming with industry, or from the plains springing into life behind the ploughshare.

The object of professional orientation is to react against social prejudices by placing the wounded soldier in the position for which he is fitted, in order to realise his full economic output.

CLIV.—(c) THE TIME REQUIRED FOR RE-EDUCATION.—HOME OR COTTAGE INDUSTRIES.—But the technical department of the school will be consulted by the pupils for all sorts of reasons : some wishing to undergo a course of physiological training, which seems full of promise ; others seeking some improvement of their prothetic appliances, or to their more careful adjustment, or simply—and I have had thousands of such before me—a circumstantial examination of their capacities, in order that they may obtain their certificate of qualification ; this they will send to manufacturers inclined to employ them, or they will profit by it directly by setting up on their own account. For my part, I hope to see this effort to revive the life of the *complete workman*, the home-worker, encouraged. In this there would be nothing inconsistent with the tendency toward industrial centralisation, as the large workshops would, without loss to themselves, become accustomed to leave the smaller crafts and petty commissions to this class of worker, a class capable of great ingenuity and inventive power. The State also would benefit by this condition of affairs, provided the home-workers did not fail to turn out good apprentices.

As for the workshops which are established for purposes of re-education, their object is perfectly well defined : to perfect the technique of the handicrafts, and to adapt the wounded soldier to selected professional exercises, accordingly as he is obliged to change his calling or to specialise in that one of the departments of his craft which is best calculated to husband his energies without diminishing their output.

The *time* required for this re-education varies. Although as far as manual labour is concerned a year constitutes a sufficient average, it must be remembered that the theoretical education will require a longer time ; and it will be of a

to work with machine-tools, which will in future be employed by the industrial world even more widely than at present. The mental vivacity which is one of the characteristics of the French people will greatly contribute to this professional adaptation.

Fig. 132.—One-armed Worker cutting Wood by means of a Rip-saw.

If, on the other hand, we bring to these questions that determination to realise the facts which is incumbent upon us, we perceive that only an exasperating prejudice has prevented the majority of crippled workers from obtaining employment, and that it has affected soldiers more than civilians. It is truly to offer an insult to glory to exclude it from our work-

shops, humming with industry, or from the plains springing into life behind the ploughshare.

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complete nature, so that it may form a working class *élite* which will itself be qualified to teach.

The principle of the school will be that of the boarding-school, the men receiving board and lodging, while their wages will be reckoned according to a scale which may vary according to locality, remembering that the loss of output in the majority of cases of amputation of the lower leg or thigh is practically *nil*.

Under exceptional circumstances it may be useful to adapt the system of the *day school* in the case of married cripples, so that they may return to their own homes every evening. Thus the schools established for the purpose of re-education distribute the benefits of instruction in pursuance of a definite aim ; they develop the minds of the workers, and complete their technical training. They determine, being familiar with the facts of the case, the industrial or commercial destination of the wounded soldier, preparing him securely to find employment and to take his place in the ranks of society.

CLV. Finding Employment.—For everything must converge upon the real object, which is to find employment for the wounded soldier. The mutilated workmen who are helped to set up for themselves, the young men who ought to enter the liberal professions, and whose efforts should be encouraged by subventions or by gratuitous training—these are examples of the men for whom we are finding employment. One may also count upon individual initiative. This or that employer or factory-manager will apply to you for one or several wounded soldiers. I, personally, have received many applications of this kind, to which I have responded by sending to the applicant the required number of war-cripples, who have undergone their course of re-education and received their certificates. These certificates constitute an element of great value, because the employer finds in them information which is intelligible, exact, and honest. Between him and his employee a solid confidence is established, the foundation of which is the truth.

A number of charitable societies have undertaken, during the war, to collect and centralise offers to employ war-cripples, and to elicit others by advertisements in the Press, or through the personal influence and connections of their directors. Beyond a doubt some of these societies have in this direction furnished a generous contribution of patriotic zeal. But to all attempts of this kind the more substantial influence of the syndical chambers is to be preferred (Trade Union Councils). I am strongly of opinion that the Trade Unions should be invited to collaborate in the work of placing our wounded and mutilated soldiers. The great factories are in a position to employ many thousands of them, provided they practise the division of labour, and lay down machinery which is easily controlled. The Ministries of Munitions in France and England, some of whose works employ from 5,000 to 10,000 hands, ought to have adopted this course long ago, and might have done so without diminishing the level of production.

They possess means of action superior to those of other Ministries.[1]

Certain great industries, especially the metallurgical, have begun to make such attempts, of their own proper motion, yielding to the spirit of solidarity which the intelligent employer feels in respect of his wounded workers. I trust that this example will rapidly become contagious.

Commerce also offers outlets : the wounded soldier may find employment as house-surveyor, newspaper canvasser, newsagent, or newsvendor. Young men who, for lack of apprenticeship to a trade, would adopt the calling of news-vendor, should be taught other trades, in which their arms or legs would be necessary. Book-keeping will absorb a certain

[1] After twenty-one months of war I read in the newspaper that the Under-Secretary of State for Munitions had " invited the heads of industries to arrange for the employment of war-cripples in all cases where it is possible to utilise them ; as watchmen, inspectors, clerks, etc." (*Le Journal*, 27 April, 1916.) A more recent " invitation " " to ascertain the kinds of work on which the interested party (wounded or crippled soldier) can be employed without inconvenience " (*ibid.*, 22 June, 1916), obviously constituted a perceptible step forward. Since then the Ministry has brought about the extensive employment of such workers.

number of wounded soldiers, above all those who are suffering from radial paralysis, and those who have lost a leg. Banks, business houses, etc., will employ them as typists, copying clerks, accountants, etc.

The essential thing is to *prepare* the wounded soldier for his calling, so that he may practise it *effectively*; then his position will be secure, and he will escape the hazards of *charitable employment.*

At the present moment the French Ministry of Labour is making an effort, thanks to a Central Office (decrees of March, 1916), to co-ordinate the scattered training establishments and employment agencies, and to repair, if possible, the mistakes which have been committed.

CLVI. An Institute for the Organisation of Labour.—It
will be seen that a complete preliminary study of the problem was necessary before it was possible to obtain a thorough grasp of the methods of re-education. It was also necessary to examine all the modes of its application, and to act with decision and promptitude, in collaboration with qualified persons, grouped under a vigilant director. Lastly, it was indispensable to possess a *central organism*, comprising all the mechanism of control and co-ordination. The school to be installed in Paris might, under the name of the " Institute for the Organisation of Labour," become the organisation in question : it might serve as a centre of advanced instruction in the disregarded science of labour and apprenticeship, and as a connecting link between the competent departments of the several Ministries, and might introduce a little order into a condition of affairs which is of necessity confused.

Let us, in fact, consider the diversity of the departments which occupy themselves with the lot of the wounded soldier. In France the Service de Santé (Army Medical Service) is responsible for matters of prothesis and psychotherapy, for the discharge of soldiers from the army, and for the award of pensions. General and technical instruction, apprenticeship, and all the legislation which surrounds them, together with the award of pensions other than military, unemployment,

and industrial accidents are the province of the Ministries of Labour, Commerce, Public Instruction, and Agriculture. The whole Government is therefore engaged in this social task, but it is advisable that a single mechanism should undertake it.

Such seems to be the mature decision of Parliament, since it has entrusted the Ministry of Labour with the duty of organising professional re-education in France. Thus a formidable waste of time and money will be avoided ; and unemployment will be prevented. It should indeed be inexcusable in countries in which the entire energy of the nation is required. I believe the scientific method of re-education will produce, in both employers and workers, an improved industrial discipline, and a higher moral and intellectual standard. As soon as the schools are in full working order, and employment secure, two years will not elapse before all our re-educated wounded soldiers will be in a position to gain their livelihood, without owing anything to any one. Our workers, artisans and peasants alike, are counting on this : they are awaiting the action of the State with an impatience whose rapid contagion I have often regretted. No one must betray the hopes which have shone into their hearts. It is the time for decisive action, for a great obligation of solidarity is at issue, of which the likeness is not to be found in human history.

CLVII. Relief Work.—The Seriously Wounded.—The
physiological organisation of labour has an immensely wide bearing, since it embraces physical education and apprenticeship, social hygiene, and professional re-education.

In the special class of wounded soldiers we have seen that it enables the very great majority of infirm, weakly, and invalid subjects to return to normal life, and about 80 per cent. of the mutilated soldiers, of whom there are in Europe more than 2,500,000.[1]

But the others, the *seriously wounded ;* those who have had to suffer a double amputation, and those who are totally

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[1] There are nearly 80,000 in France, as against 2,781 after the war of 1870-1. The belligerent countries number, on an average, *one wounded soldier per 30 inhabitants.*

invalid, and, lastly, the *blind*? What can the scientific
method of re-education do for these unfortunates? Some
possess a degree of functional capacity so small that it cannot
be used; some are only in slightly better case. Others
—even when their limbs are intact—have lost the most
important of the functions of relation: their *sight*. For them
the outer world has become a place full of ambushes; a
heavy darkness has descended upon the horizon which met
their eyes of old, and which, to them, was familiar.

All these facts I reserved for the present chapter, since
they did not immediately enter into my programme, and
because the *normal social output* alone preoccupied me. I
should like, however, to venture on a brief survey of the
problem of charitable employment or relief work upon which
the *seriously wounded* and the *blind* are dependent. I do
not intend to attempt more than a mere contribution to the
subject.

The equipment with prothetic appliances of those who have
lost two or more limbs is a delicate matter, which demands
the fullest attention. The remedy is a perfected prothesis,
adapted as carefully as possible; a prothesis utilitarian
rather than aesthetic. The lower limbs require less care.
The patient, with two good " pestles," can enter some seden-
tary occupation; walking is comparatively easy, but the
man must be his own master; he must be master, too, of
his time, and able to study his own convenience.

The literally legless man, when he is poor, can only have
recourse to benevolent assistance; it is his right. *Special
workshops* would permit of the utilisation of this category of
worker, whose output is often fairly high. The category of
those who have lost both arms or hands is more interesting,
if we may say so; for scientific re-education benefits it very
greatly, both by exercising and training the sensitiveness of
the stumps, and by adapting them to the execution of dexterous
movements. Never has this physiological training appeared
more fruitfully beneficial than in the case of the *blind*.

The appliances of the Cauet type are those which best
satisfy the needs of those who have suffered amputation of

both the upper limbs, who, if they are intelligent, can resume

Fig. 133.—Accountant, seated at a Café Table. Both his Fore-arms
have been amputated.

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CLVIII. The Physiological Education of the Blind.—The better to define the principles here involved, I will take the example of a blind soldier who had suffered amputation of the left upper arm and the right fore-arm.

G. S., aged 41 years, married, and the father of two children, was a dealer in forced fruits and vegetables. In his calling the senses play an essential part. The man was utterly dejected as a result of his mutilations. I took him, barely cicatrised, from the hospital in which he was stifling his mental anguish, and I busied myself at first with the sensibility of the stumps.

Here is the method employed :

For a week the sensibility is trained by means of the weighted *bracelet* (§ 112).

This training is completed by exercises with the brachial splint, and controlled by the *spike aesthesiometer* and the *pressure dynamometer*. Finally the *aesthesiographic table* is employed (Fig. 134). This consists of a rectangular plate of brass, P, with a flue, F, which is placed over a small lamp, bringing the whole up to a temperature of about 86° Fahr. In the centre of the plane surface appears a blunt point of ivory, I, which by means of a micrometer screw, M, can be gradually made to protrude. The extent of this protrusion is, of course, known. At its base it presses on a Marey drum, with an internal spring, and the pressure can be registered as usual. Under these conditions the patient is allowed to explore the surface of the plate or table, the point being at zero. He moves his stump over it in all directions ; and little by little the micrometer screw is turned. When the patient manages to detect the ivory point, the height of the projection of the point is read, and the pressure which the stump has exerted in order to feel it is registered.

From day to day the results improve. The patient is now provided with *mechanical arms* of Cauet's type, and the sensory re-education is recommenced, but is now combined with the adaptation of the movements. G. S. has succeeded in making himself useful in his old occupation ; he no longer feels isolated ; he is re-entering into possession of the active life which at one time he thought he had left for ever. We live by our

senses, a little of necessity and a great deal by habit. The blind man has to *lose* the habit, and content himself with the necessity.

CLIX. The Work of the Blind.—The loss of sight is more grievous to some than to others. The man congenitally blind has no conception of his loss : the man blinded by accident, on the other hand, attaches to it an importance

134.—Employment of the *Aesthesiographic Table* in the Case of a blind Cripple.

which depends on the sum of the delights of which it deprives him. The simple-minded man suffers, in this respect, less than the cultivated man. But one must continually appeal to the *moral* of the blind, and employ the finest tact in dealing with them.

The best means of fortifying their *moral* is to find *work* for them, and preferably to re-adapt them to their old trades.

Work manifests the action of man upon the external world, and draws him away from the anxieties, the griefs, and the

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Work manifests the action of man upon the external world, and draws him away from the anxieties, the griefs, and the

discouragement which have from all time been the lot of the blind :

O Sminthée Apollon, je périrai sans doute
Si tu ne sers de guide à cet aveugle errant !

" O Smintheus Apollo, I shall surely die if thou dost not serve as guide to this wandering blind man ! "

But the god of shepherds is assuredly less useful than a poodle to guide the blind farmer across the fields. For it seems to me necessary to adapt the latter to the *work of the soil* and the tasks of the farmyard. He has, in short, the necessary experience ; he is familiar with aspect and the use of agricultural implements. Well-trained as regards his tactile sensibility, and, at need, assisted by a boy, he can resume the laborious life of the peasant. For the peasant farmers form the majority of those engaged in agriculture.

Such is the case of L——, among others ; a small farmer smitten with blindness in the war, who, further, lost the four fingers of his right hand, the thumb having retained a certain though insufficient mobility. The artificial hand with which I equipped him enables him to make use of the universal ring or pliers, or even of the parade hand. His movements are being controlled and corrected, thanks to the *dynamographic shovel*, and his efforts evaluated, with a view to the possibility of the necessary exertions. There are in general no practical difficulties in enabling the blind farmer to resume his old occupations, except, indeed, that it is important to make it easier for him to do so. If he has no kinsfolk who can employ him, some benevolent society must place him in surroundings which are familiar to him.

In general the process of re-adaptation to work should be the object of benevolent assistance, for it economises the whole business of getting to work again, and of apprenticeship. I have always, for example, recommended that blind men who belong to the category of mechanicians, tinsmiths, locksmiths, etc., should be re-educated as fitters, and in the performance of heavy mechanical work. The Reuilly establishment has completely realised the force of my contention.

These men work by the *task* and are paid by the piece, neither more nor less than the normal workers in the factory. Here is a profession in which our great manufacturers can encourage the pious work of assisting the blind.

The trades in which re-adaptation and even re-apprenticeship are easy may be classified as follows, in the order of useful output : agriculture ; coarse mechanical work ; book-binding ; brush-making ; mending and re-seating chairs ; basket-making ; packing (closing boxes of fruits and vegetables) ; cooperage ; making wooden shoes ; making small baskets of raphia ; massage ; piano-tuning ; telephoning (for customers).

It is in all cases advantageous to train and exercise the sensibility by contact with the surfaces and the contours of tools and shaped articles ; for example, by utilising a cube of brass with rounded corners, the radius of the various rounded surfaces being unequal, and getting the blind man to recognise and estimate the differences. The chair-mender will pass his fingers over the straw, rushes, or cane of the chair-bottom, counting the rows and inequalities of the prepared surface ; and so with other kinds of work.

I have caused little tablecloths to be made of silk or cotton twist, for tea-tables. Sweaters, mufflers, etc., can be made in the same sort of work. It is very easy to learn and very remunerative.

These brief explanations will enable the reader to realise how much thought might be given to the subject of relief by means of work, a species of relief which affects so many unfortunates, and which snatches them from a cruel fate, while it extends the scientific work of organising human activity to ground which we shall never tread without a profound emotion and a pious respect.

CLX. General Conclusion.—Through the innumerable forms of our activity, in the exertions of the body as well as in those of the mind, a single principle appears : the principle of *order and harmony*. All Nature obeys it : the ray of light, as it is refracted or reflected, follows the shortest

path ; the stone which falls or is thrown from the hand describes a minimum trajectory ; the instinctive movement is also the most rapid. And man has never reflected that his voluntary actions squander time and energy and riches which would benefit society ! For he needed self-control and a rigorous science to avoid useless waste, and to keep himself on the sloping path of routine. A demonstrative experience was necessary to make him understand that economy, while husbanding the expenditure of our energies, increases their utilisation, and that this expenditure should be rational and methodical in every sphere which is open to our activities.

For it is a mistake to suppose that the capital of our physical and psychical energies is inexhaustible. It represents a sum, a total, of which we do not know the exact figure, but it cannot be far from the equivalent of 150,000 horse-power hours for the normal duration of life, with a *useful* effect of about 10 per cent.

This would be a very small mechanical output in comparison with that of inanimate motors, if we had not to consider the intelligence of labour and its infinite variety, if it were not for the existence of *thought*, which nothing hitherto has been able to parallel.

The athlete is mistaken when he crazily dissipates his strength. The working-man is making a miscalculation when he refuses to improve the condition of his work by a more skilful technique, an improved equipment, and a judicious employment of his working day. The employer is mistaken when he rejects the employment of wounded or mutilated soldiers, a considerable reinforcement of the normal workers, and an important source of profit ; and in general we misconceive the profound and veritable laws of social organisation if we fail to put each man in the place which should properly be his if he is to yield his full output. The day has come for a conception of this organisation which is at once scientific and humane, and a source of concord and well-being.

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